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European Refuse Fired Energy Systems: Evaluation of Design Practices. Volume V: Werdenberg-Liechtenstein Plant, Buchs, St. Gallen, Switzerland

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The evaluation, which consists of two volumes of text and 15 trip reports, analyzes the experiences of the Europeans with waste to energy systems. The text is a compilation of the data obtained during visits to 15 major European refuse fired energy systems and visits to systems vendors, government agencies and other plants.

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Werdenberg-Liechtenstein Plant
Buchs, St. Gallen, Switzerland

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Volume 5

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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TABLE OF CONTENTS

	Page
PREFACE	i
ORGANIZATION	ii
ACKNOWLEDGEMENTS	iii
STATISTICAL SUMMARY	iv
Werdenberg Plant	v
DEVELOPMENT OF THE SYSTEM	1
COMMUNITY DESCRIPTION	1
Geography	1
Government and Industry	3
SOLID WASTE	5
Solid Waste Generation	5
Solid Waste Collection Activities	10
Solid Waste Transfer and/or Pretreatment	10
Solid Waste Disposal	11
REFUSE-FIRED STEAM GENERATOR EQUIPMENT	11
Furnace Hopper and Feeder	16
Burning Grates	17
Furnace Wall (Combustion and First Pass Radiation Chambers)	20
Second Boiler Pass	23
Superheater	23
Boiler (Convection Section)	24
Economizer	25
Boiler Water Treatment	25
Primary (Underfire) Air Supply	26

TABLE OF CONTENTS (Continued)

	Page
Secondary (Overfire) Air Supply	26
Tertiary (Sidewall) Air Supply	29
Heat Release Rate	31
Energy Utilization Equipment	32
POLLUTION CONTROL EQUIPMENT	41
Wastewater Discharge	42
Stack Construction	42
POLLUTION CONTROL ASSESSMENT	43
Noises	44
PERSONNEL AND MANAGEMENT	44
ENERGY MARKETING	46
ECONOMICS	46
Capital Investment	46
REVENUES	47

LIST OF FIGURES

FIGURE 1-1a.	REFUSE GENERATION AREA SHOWING THE SERVICE AREAS IN THE CANTON OF ST. GALLEN AND IN LIECHTENSTEIN	2
FIGURE 1-1.	PLAN OF WERDENBERG PLANT SHOWING RELATION TO ASSOCIATED COMMUNITY SERVICE FACILITIES	2a.
FIGURE 1-2.	PROFILE OF PLANT SURROUNDED BY MOUNTAINS	4
FIGURE 1-3.	SOLID WASTE COLLECTION RATES	6
FIGURE 1-4.	SWISS NATIONAL SOLID WASTE DISPOSAL PATTERNS FROM "WOHIN MIT DEN ABFALLEN", ZURICH, NOVEMBER 1976	12

LIST OF FIGURES (Continued)

		Page
FIGURE 1-5.	TRUCK DELIVERING TO REFUSE BUNKER	14
FIGURE 1-6.	CONTROL ROOM WITH SCALE OPERATOR, CRANE OPERATOR AND PLANT CONTROL ROOM OPERATOR	14a.
FIGURE 1-7.	OVERALL SECTION INSIDE THE WERDENBERG PLANT	15
FIGURE 1-8.	AN EXAMPLE OF THE ALBERTI FONSAR STEP GRATE SYSTEM ASSEMBLED AT THE FACORY	18
FIGURE 1-9.	SECTION THROUGH WERDENBERG-LIECHTENSTEIN WASTE-TO-ENERGY PLANT	21
FIGURE 1-10.	SCHEMATIC VIEW OF WERDENBERG-LIECHTENSTEIN WASTE-TO-ENERGY PLANT	27
FIGURE 1-11.	SKETCH OF AIR FLOWS TO FURNACE	28
FIGURE 1-12.	WERDENBERG STEAM AND HOT-WATER DISTRIBUTION SYSTEM	33
FIGURE 1-13.	OIL-FIRED STANDBY BOILER ON TRANSPORT TRUCK	34
FIGURE 1-14.	STEAM TURBO GENERATOR	35
FIGURE 1-15.	TWO VIEWS OF AIR-COOLED CONDENSER AT WERDENBERG . .	36
FIGURE 1-16.	STEAM AND HOT WATER DISTRIBUTION TRENCH AT WERDENBERG	37
FIGURE 1-17.	CASCADE TYPE WATER HEATER ON LEFT, FEEDWATER TANK AND STEAM LINES ON RIGHT AT WERDENBERG	38
FIGURE 1-18.	INSULATION, INSTALLATION AND MAP OF HOT WATER DISTRIBUTION SYSTEM AT WERDENBERG	39
FIGURE 1-19.	APARTMENT HOUSE AT WERDENBERG HEATING BY HOT WATER FROM STEAM PLANT	40
FIGURE 1-20.	ORGANIZATION CHART FOR OPERATION OF WERDENBERG PLANT	45

LIST OF TABLES

		Page
TABLE 1-1.	DELIVERIES FROM THE COMMUNITES SERVED IN 1976 (FROM PLANT REPORT).	7
TABLE 1-2.	DELIVERIES IN EACH MONTH IN 1976 AND TOTALS FOR 1975 AND 1976 (FROM PLANT ANNUAL REPORT).	8
TABLE 1-3.	REFUSE COMPOSITION AT THUN, 1975	9
TABLE 1-4.	REFUSE UTILIZATION IN SWITZERLAND IN 1975 (FROM "WOHIN MIT DEN ABFALLEN", ZURICH, NOV. 1976)	13
TABLE 1-5.	WERDENBERG PLANT COSTS, 1976	48
TABLE 1-6.	REVENUE ESTIMATE FOR 1977	49

PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
Z APPENDIX

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Robert Giger, Plant Manager
Hansruedi Steiner, Widmer & Ernst
Peter Nold, Widmer & Ernst
Theodor Ernst, Widmer & Ernst
Robert Hardy, U.S. Representative, Widmer & Ernst

STATISTICAL SUMMARY

Werdenberg Plant -

Community description:	
Area (square kilometers)	900
Population (number of people)	76,685
Key terrain feature	mountainous
Solid waste practices:	
Total waste generated per day (tonnes/day)	71.8 (365-day yr)
Waste generation rate (Kg/person/yr)	342
Lower heating value of waste (Kcal/kg)	2300-3360
Collection period (days/week)	5
Cost of collection (local currency/tonne)	
Use of transfer and/or pretreatment (yes or no)	No
Distance from generation centroid to:	
Local landfill (kilometers)	5
Refuse fired steam generator (kilometers)	
Waste type input to system	mixed community and bulky
Cofiring of sewage sludge (yes or no)	no
Development of the system:	
Date operation began (year)	April, 1974
Plant architecture:	
Material of exterior construction	Plastic coated steel
Stack height (meters)	40
Refuse fired steam generator equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	Approximately 25 percent
Lower heating value (Kcal/kg)	2300-3360
Volume burned:	
Capacity per furnace (tonnes/day)	120 (for 2800 Kcal/kg)
Number of furnaces constructed (number)	1 (room for 2)

Capacity per system (tonnes/day)	120
Actual per furnace (tonnes/day)	133
Number of furnaces normally operating (number)	1
Actual per system (tonnes/day)	133 (5 days/week)
Use auxiliary reduction equipment (yes or no)	No
Pit capacity level full:	
(Tonnes)	---
(m^3)	1300
Crane capacity:	
(tonnes)	5
(m^3)	2
Feeder drive method	Hydraulic
Burning grate:	
Manufacturer	Alberti-Fonsar
Type	Stepped reciprocating
Number of sections (number)	7 steps long
Length overall (m)	7.0
Width overall (m)	2.5 (effective)
Primary air-max (m^3/hr)	32,000 m^3/hr (20 c)
Secondary and tertiary air-max (m^3/hr)	26,400 m^3/hr (20 c)
Furnace volume (m^3)	142
Furnace wall tube diameter (cm)	7.61
Furnace heating surface (m^2)	200 (approx.)
Auxiliary fuel capability (yes or no)	Yes
Use of superheater (yes or no)	Yes
Boiler	
Manufacturer	Alberti-Fonsar
Type	Natural circ. water tube
Number of boiler passes (number)	3
Steam production per boiler (t/hr max)	16
Total plant steam production (t/hr max)	16
Steam temperature (^oC)	395
Steam pressure (atm)	40

Use of economizer (yes or no)	Yes
Use of air preheater (yes or no)	No
Use of flue gas reheater (yes or no)	No
Cofire (fuel or waste) input	No
Use of electricity generator (yes or no)	Yes
Type of turbine	Back pressure
Number of turbines (number)	1
Steam consumption (t/hr)	14 t/hr
Electrical production capacity per turbine (mw)	0.8 mw
Total electrical production capacity (mw)	0.8 mw
Turbine back pressure (atm)	5.5-12 (range)
User of electricity ("Internal" and/or "External")	Internal, external
Energy utilization:	
Medium of energy transfer	Steam, hot water
Temperature of medium (^{o}C)	110-180 (water)
Population receiving energy (number)	500 plus industry
Pressure of medium (atm)	steam 10
Energy return medium	Water
Pollution control:	
Air:	
Furnace exit conditions	
Gas flow rate (m^3/hr)	83,000 (274c)
Furnace exit loading (mg/Nm^3)	88 at 7% CO_2

Equipment:	
Mechanical cyclone collector (yes or no)	No
Electrostatic precipitator (yes or no)	Yes
Manufacturer	Elex
Inlet loading on precipitator (mg/Nm^3)	300
Exit - leading on precipitator (mg/Nm^3)	88 at 7% CO_2
Legislative requirement (mg/Nm^3)	100 at 7% CO_2
Scrubber (yes of no)	No
Inlet loading:	---
H Cl (mg/Nm^3)	---
H F (mg/Nm^3)	---
Exit loading:	
H Cl (mg/NM^3)	---
H F (mg/Nm^3)	---
Legislative requirements (mg/Nm^3)	---
Other air pollution control equipment (yes or no)	Duray Dr 280
Water:	
Total volume of waste water (liters/hr)	360
Ash:	
Volume of ash (tonnes/day)	40
Volume of metal recovered (tonnes/day)	4

DEVELOPMENT OF THE SYSTEM

As the waste disposal problem evolved in this area, three of the larger communities--Buchs, Switzerland and Vaduz and Shann (in Liechtenstein)--began discussions of possible solutions. Because some years ago composting plants were in vogue in Switzerland, they decided to build one in Werdenberg. It cost about 1,000,000 S.Fr. (then about $250,000) and began operation in January, 1962. But gradually the plant became too small for the amount of waste being generated so Incinerator I (without heat recovery) started operation in January, 1968. It cost about 2.5 million S.Fr. However, waste generation continued to increase at the rate of 20 percent per year and in mid-1969, it was decided that Incinerator I was too small. Accordingly, in 1970, the local Vereins für Abfallbeseitigung (Society for Waste Management) invited proposals for a new incinerator, a waste-to-energy plant.

In December, 1971, the proposal of Widmer + Ernst was accepted and in January, 1972, construction began adjacent to the old incinerator and compost plants (see Figure 1-1). The plant was built in about 28 months and operation began in April, 1974. It was dedicated on November 22, 1974 and provisional acceptance was made in July, 1975. Operation continued after the dedication while adjustments were made to firing rate and to component operation. The plant was accepted November 1, 1975.

COMMUNITY DESCRIPTION

Geography

This relatively new and colorful plant named Werdenberg-Liechtenstein is located on the Werdenberger Binnenkanal (Inland Canal) paralleling the Rhine River on the border between eastern Switzerland and Liechtenstein. (See Figure 1 -1a) Actually the plant is located in the city of Buchs, Switzerland. The name "Werdenberg" comes from a very small neighborhood that is at the inside edge of Buchs. The region's area is roughly 900 square kilometers (345.3 square miles).

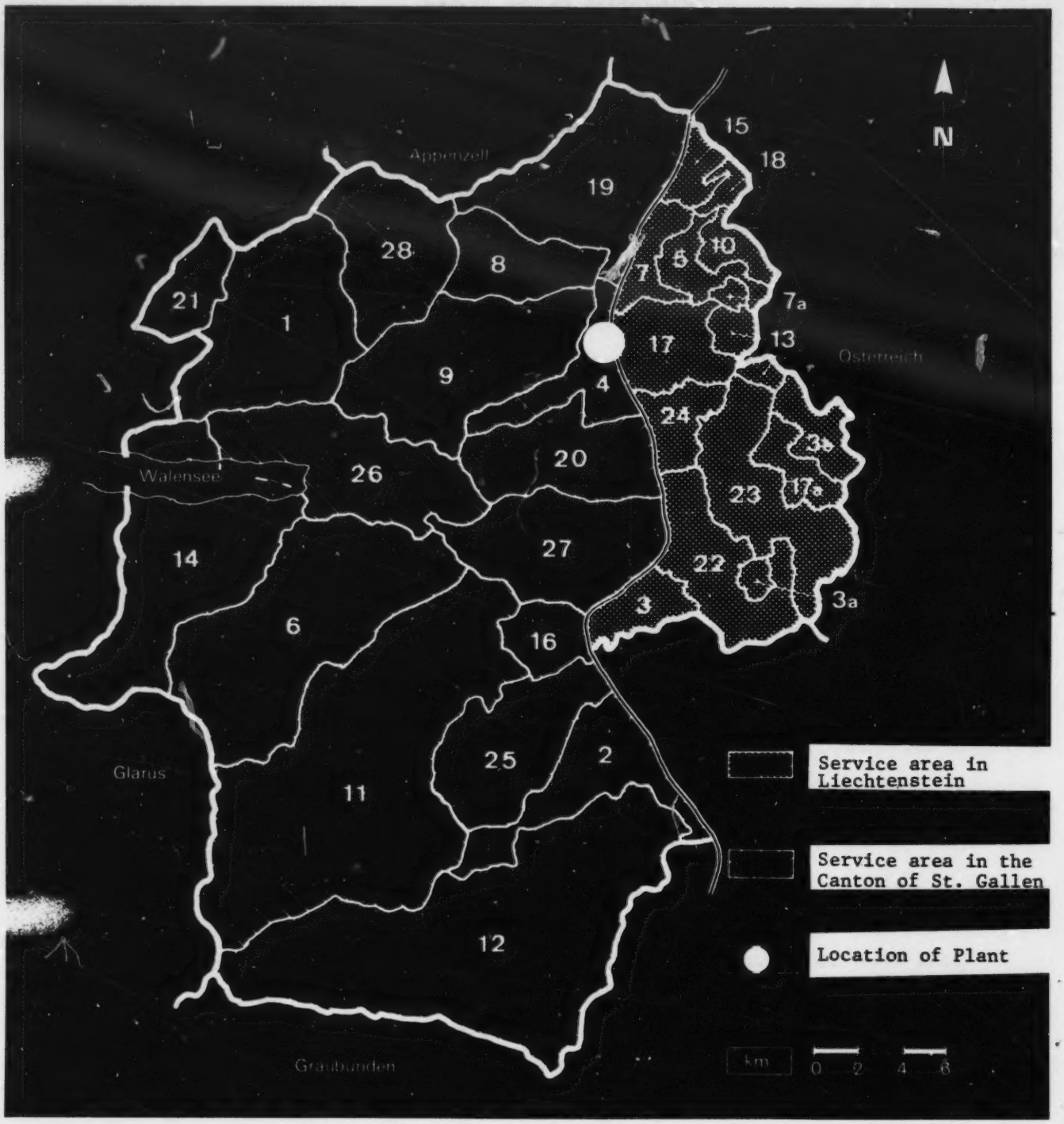
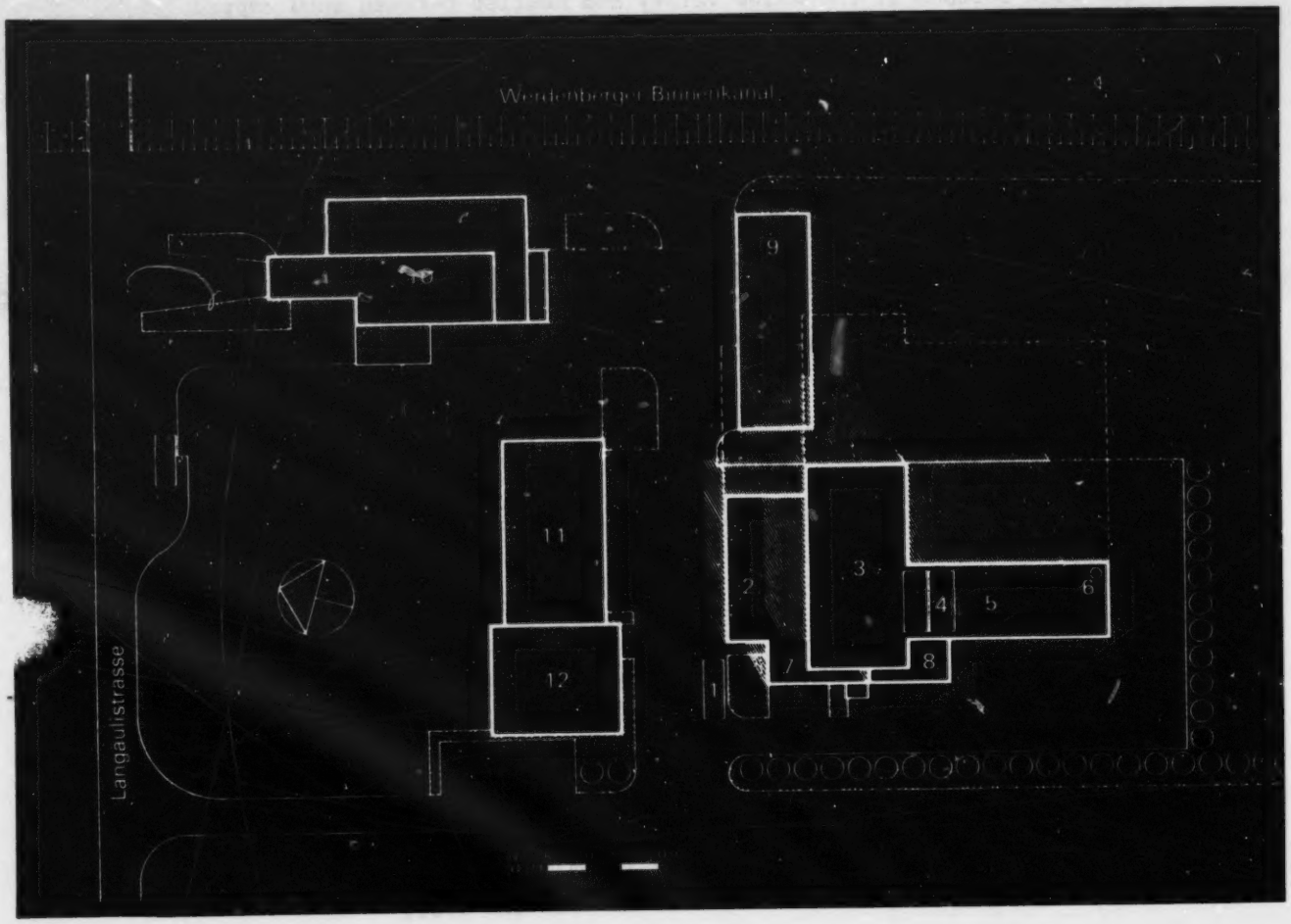


FIGURE 1-1a. REFUSE GENERATION AREA SHOWING THE SERVICE AREAS IN THE CANTON OF ST. GALLEN AND IN LIECHTENSTEIN.
Werdenberg-Liechtenstein Plant Courtesy of Widmer + Ernst (Alberti-Fonsar)



1 Truck scale
2 Tipping area
3 Waste pit
4 Air-cooled condenser
5 Furnace room
6 Steel chimney
7 Central control room
8 Feedwater treatment
9 Waste storage
10 Old incinerator
11 Service building
12 Offices and locker rooms

FIGURE 1-1. PLAN OF WERDENBERG PLANT SHOWING RELATION TO TO ASSOCIATED COMMUNITY SERVICE FACILITIES (COURTESY OF WIDMER & ERNST. ALBERTI FONSAR)

The setting and terrain are most picturesque. The plant is set on the flat bottoms of the Rhine Valley and nestled between snow capped mountains. (See Figure 2.) Being so close to the canal did present foundation problems and additional costs were incurred.

Buchs itself had a 1970 census population of 8,570 while the total waste generating region had 76,685 inhabitants. After the Swiss referendum in 1975 loosely labeled, "Swiss for the Swiss", the population declined as Mediterrenean workers returned to their native lands. The population in 1977 is likely equal to or less than the 1970 figures.

The community population is somewhat seasonal with more people during the winter skiing and summer vacation seasons.

Government and Industry

The government and industry employment sectors are stable with respect to growth.

In this region of two countries and 28 cities, there are 17 Switzerland counties and 11 Liechtenstein counties. All of the Swiss counties are within the Canton (state) of St. Gallen.

The industrial base is varied with the following composition:

- International headquarters for Hilti fastening systems (metal and explosives) [in the past, Hilti sent sintered magnesium pellets to the plant.]
- Hoval household boilers
- Textile manufactures (trimmings)
- Carpet manufactures (trimmings)

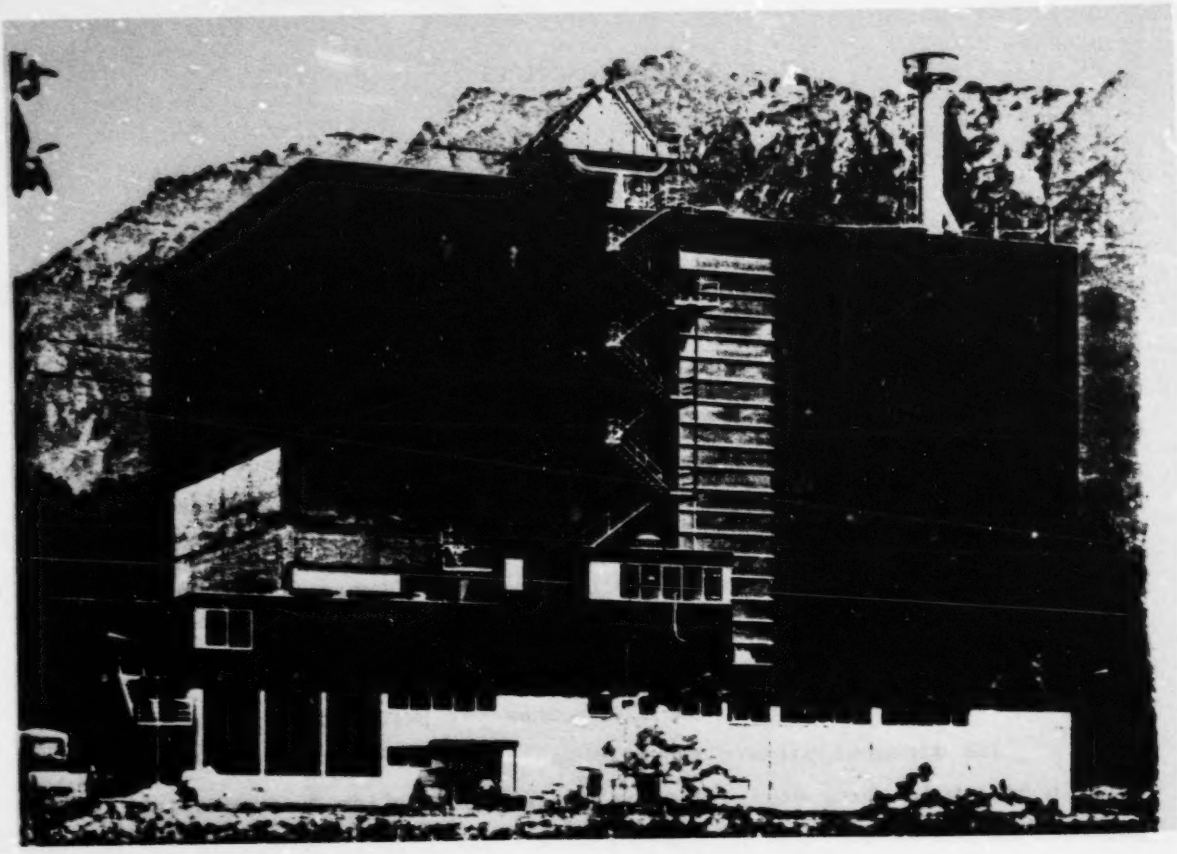


FIGURE 1-2. PROFILE OF PLANT SURROUNDED BY MOUNTAINS
Werdenberg-Liechtenstein Plant
(Courtesy of Widmer + Ernst (Alberti-Fonsar))

- Screen printing firm
- Plastic tape manufacturer (plastic trimmings)
- Leather shoe manufacturer (leather trimmings)
- Petroleum storage
- Fruit preserves processing plant (large tin cans)

SOLID WASTE PRACTICES

Solid Waste Generation

Figure 3 presents the annual pattern from 1962 to 1973 for animal, bulky scrap iron, industrial, household and total waste collected. The rise from 4,000 tonnes (4409 tons) in 1962 to 24,000 tonnes (26,455 tons) in 1973 must be interpreted carefully. First, these are collection rates and not generation rates. In other words, there are fewer people throwing refuse over the hill and more providing their waste to collectors. Secondly, the Society for Refuse Management has been expanding its geographic territory as more communities decide to join.

Table 1 displays the collection of various types of wastes by the communities and their respective populations. These 76,685 people had 26,190 tonnes collected during 1976 for an average generation/collection rate of 342 kilograms per person per year (754 pounds per person per year).

The seasonal pattern shown in Table 2 depicts a 11.7% 1975 to 1976 rise in household waste collections versus a 2.8% decline in industrial collections for an overall increase of 7.3%. The rise in household collections came about because more communities have recently been added. The fall in industrial pickups coincides with the European and especially the Swiss recession. Neither an influx of people nor increased waste generation rates could have contributed to the dramatic increase in household collections.

A recent national report presented composition as had been measured as Thun, Switzerland in 1975. See Table 3.

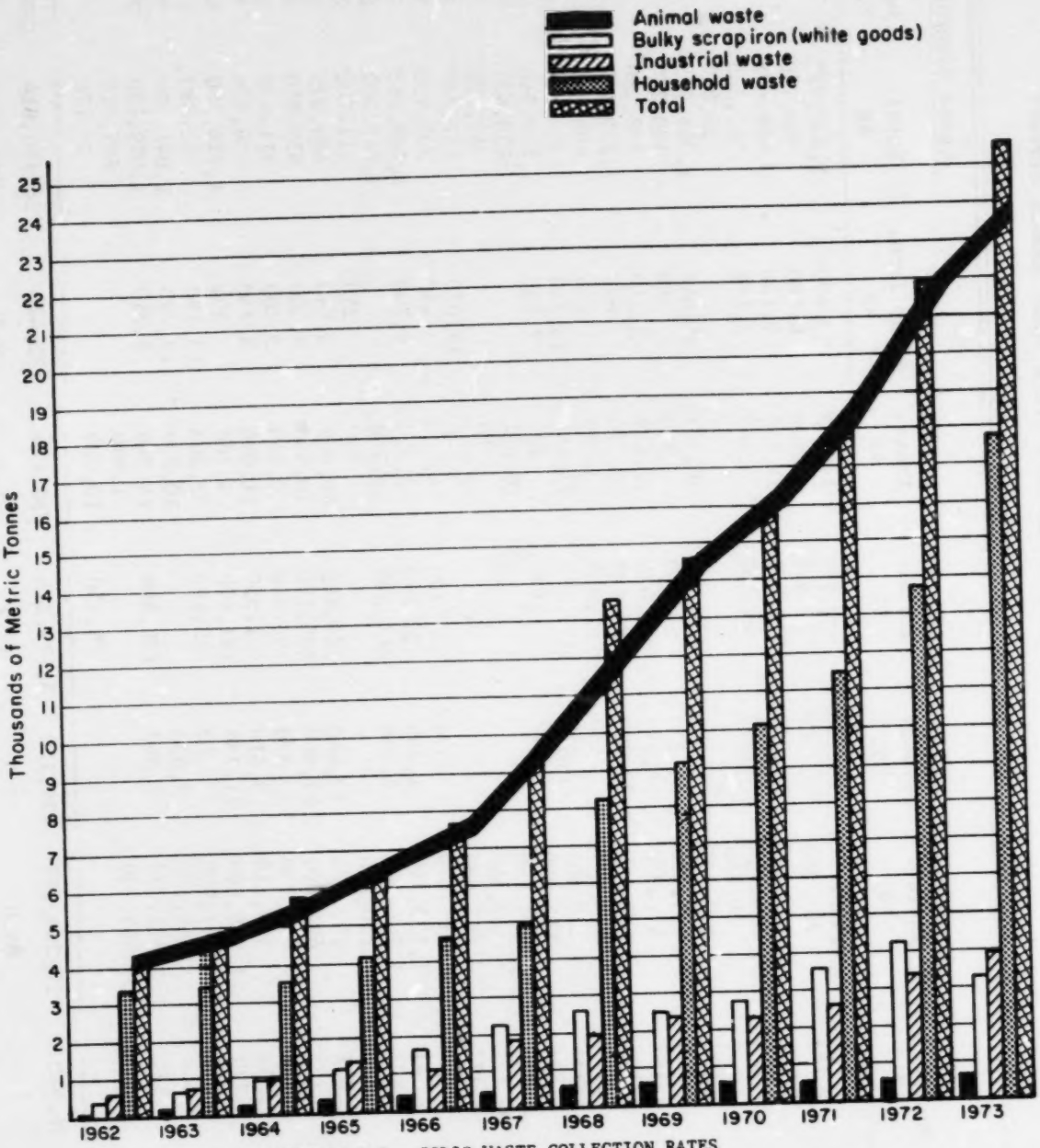


FIGURE 1-3. SOLID WASTE COLLECTION RATES
Werdenberg-Liechtenstein Plant
Courtesy of Widmer & Ernst (Alberti-Fonsar)

TABLE 1-1. DELIVERIES FROM THE COMMUNITIES SERVED IN 1976 (FROM PLANT ANNUAL REPORT)

Community	Population, 1970	Household Waste, kg	Bulky Waste, kg	Industrial Waste, kg	Animal Waste, kg	Scrap Iron, kg	Waste Generation	
							Total, kg	Per Person, kg/year
Bad-Ragaz	3,708	1,485,710	25,190	9,160	14,263	13,600	1,547,923	416
Balzers	2,703	703,060	80	27,020	5,600	4,980	740,740	274
Buchs	8,570	2,427,170	84,010	919,920	21,455	7,140	3,459,695	406
Eschen	2,104	494,260	1,980	10,150	2,745	1,190	510,325	242
Festung Sargans		59,840					59,840	
Flums	4,607	1,274,570	190	25,560	30,365	36,040	1,366,725	297
Gamprin	570	125,290	370	53,300	900	360	180,220	316
Gams	2,197	471,350	8,580	29,620	25,430	3,210	538,190	245
Grabs	4,198	1,086,400	22,880	86,800	23,370	3,670	1,223,120	291
Mauren	2,050	478,630	130	1,430	3,570	1,200	484,960	237
Mels	5,951	1,353,804	2,240	339,906	28,156	18,710	1,742,816	293
Obertoggenburg	2,881	1,146,040	4,660	1,730	270	7,240	1,159,940	403
Pfafers	1,955	444,860			10,621		455,481	233
Planken	177	47,360			360		47,720	270
Quarten	2,493	622,630			4,995	19,670	647,295	260
Ruggell	863	197,420	570	700	4,783	460	203,933	236
Sargans	3,881	1,173,760	1,280	22,710	3,718	6,700	1,208,168	311
Schaan	3,878	1,204,340	14,030	804,200	19,730		2,042,300	527
Schellenberg	513	110,810			640	250	111,700	218
Sennwald	2,651	667,580	13,440	163,860	41,405	3,590	889,875	336
Sevelen	2,735	691,200	27,560	225,150	10,540	5,360	959,810	351
Triesen	2,629	647,770	970	56,250	3,240	3,200	711,430	271
Triesenberg	1,801	539,110	3,010	1,550	11,026	3,730	558,426	310
Vaduz	3,790	1,518,280	21,730	181,620	4,760	390	1,726,780	451
Vilters	2,766	647,980	60	58,960	32,203	13,190	752,393	272
Walenstadt	3,444	1,015,150	2,830		10,239	12,790	1,041,009	302
Wartau	3,570	935,870	3,360	130,500	24,340	5,750	1,099,820	308
KVA Au		683,330			1,680		685,010	
Diverse				25,150	10,020		35,170	
Total	76,685	22,253,574	239,150	3,175,246	350,424	172,420	26,190,814	342
Percent of Total		85.0	7.5	12.2	1.3	0.7	100.00	

TABLE 1-2. DELIVERIES IN EACH MONTH IN 1976 AND TOTALS FOR 1975 AND 1976 (FROM PLANT ANNUAL REPORT)

Month	Household Waste	Bulky Waste	Industrial Waste	Animal Waste	Total Waste
Januar	1561440	14920	215090	24750	1816200
Februar	1384744	16850	515946	25375	1942915
März	1822910	32450	244410	28935	2128705
April	2070220	21370	237805	26713	2356108
Mai	1757510	14300	265385	25560	2062755
Juni	2088730	17010	233230	29170	2368140
Juli	2056470	30500	225680	29085	2341735
August	1979360	17290	234290	26025	2256965
September	1936810	16930	265560	28125	2247425
Oktober	2020540	29780	244960	37890	2333170
November	1858180	19310	252610	32795	2162895
Dezember	1716660	8440	240280	36001	2001381
Total	22,253,574	239,150*	3,175,246	350,424	26,018,394
1975	19,921,940	469,130	3,234,702	455,417	24,111,189
Difference	+2,331,634	-229,980	-89456	-104993	+1,907,205
% + -	+11.7%	-96.1%	-2.8%	-29.9%	+7.3%

Maximum Month: April 2357,298 kilogram

Maximum Day: Wednesday, 7, April = 160,000 kilogram

* This total for bulky waste includes only that for private haulers. Since 1976 all bulky waste delivered is combined in a single total.

TABLE 1-3. REFUSE COMPOSITION AT THUN, 1975

Paper	39.66%
Glass	8.31%
Ceramic	1.23%
Metal	4.80%
Wood	5.51%
Textiles, Leather, Rubber	6.04%
Plastics	6,57%
Kitchen waste	8,96%
Garden waste	13,42%
Misc.	5,50%

(From Wohin mit den Abfallen?" Zurich, November 1976)

Solid Waste Collection Activities

Throughout the region, trucks of various sizes and descriptions collect waste material. The Society for Refuse Management licenses four private companies to collect waste materials from households. The eight (8) trucks owned by these four firms make two to four trips per day. Truck sizes range from 12 to 15m^3 (15.7 to 19.6 $yards^3$). In addition, there are a few commercial private haulers and several industrial companies with their own trucks. Most crews work 8 hours per day - 5 days per week.

Three of the collection firms are paid by the Society and one is paid by his local community. All are paid on a price per ton basis as weighed at the plant scales.

Costs are distributed back to the communities based on a careful accounting of where the waste comes from. Fees have been relatively constant over the last three to four years.

Each household pays taxes to his respective community. As an example, the plant manager pays 90 Swiss francs ($36) per year for his 0.5 to 0.7 tonnes generated.

Moisture ranges from 25% to 40% with 35% being average. During the compliance test, the lower heating value was measured at 3,200 Kcal/kg (5,760 Btu/pound)[13,398 k Joules/kg] by using the refuse fired steam generator as a calorimeter. They now believe that the lower heating value is ranging from 2,300 to 3,360 kcal/kg (4,140 to 6,048 Btu/pound)[9,628 to 14,068 k Joules/kg].

Solid Waste Transfer and/or Pretreatment

There are no transfer stations or pretreatment facilities. However, there are some shopping center-type recycling centers where people can bring newspapers, bottles, and cans. Color-sorted glass can be sold for 60 SF per tonne ($26.40 per ton) while noncolor sorted glass can be sold at 40 SR per tonne ($17.60 per ton).

Solid Waste Disposal

This refuse fired steam generating building has, standing next to it, a separate composting building. For several years back in the 1960's, the national trend was to construct compost plants and also incinerators for waste material from the composting operation. At one time there were 15 to 19 such combination facilities in Switzerland. Rarely now is the local composting equipment run. Only nine are now operating in combination in Switzerland. There is only one pure composting facility now in the country.

The National Report, "Wohin mit den abtällen" shows the 1975 national pattern for solid waste disposal. See Figure 5 and Table 4.

REFUSE-FIRED STEAM GENERATOR EQUIPMENT

As has been described in previous sections, the combination of community and industrial wastes is delivered 5 days per week by eight regular trucks plus a few private ones. Incoming trucks are weighed on an 30-ton semi-automatic weigh scale which is operated by a plant worker who devotes about 1/4 time to weighing. The scale operator can barely be seen (Figure 5) as the third man at the rear of the control room. The weights, total and tare, are printed by an electro-mechanical recorder with digital readout. The scale is inspected, calibrated and serviced once per year. It is expected to last more than 20 years. Figure 6 shows a truck-delivering refuse.

Figure 7 is an overall section inside of the Werdenberg plant.

There is no provision for processing bulky waste. The crane operator is instructed to crush bulky items (up to 2m by 2m) in the pit by dropping the 3-ton grapple on the object. Large metal objects are lifted out and set aside for recycling which, in 1976, totalled 172 tonnes.

After each truck driver delivers a load to the pit he is expected to sweep up his dumping area. There are four doors to the pit but only one is used. If necessary, emergency refuse storage is available in the pits at the old compost plant next door.

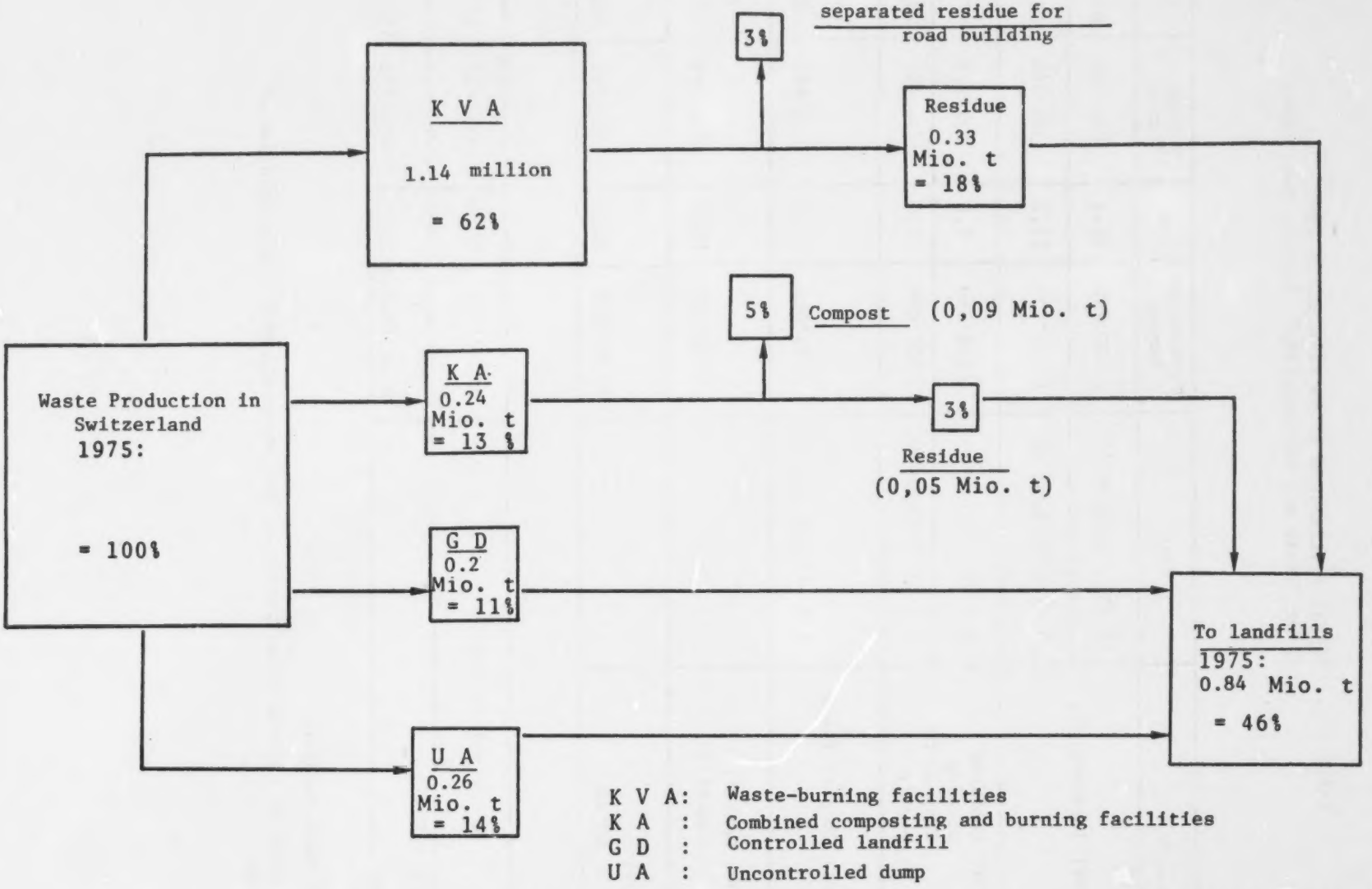


FIGURE 1-4. SWISS NATIONAL SOLID WASTE DISPOSAL PATTERNS FROM "WOHIN MIT DEN ABFALLEN", ZURICH, NOVEMBER 1976

TABLE 1-4. REFUSE UTILIZATION IN SWITZERLAND IN 1975
(From "Wohin mit den Abfallen", Zurich, Nov. 1976)

Facilities	Type	Population Served	%	Refuse Tonnes	%.
42 (65%) Incinerators	13 (20%) With HR 1)	2'560'720	39,8	805'380	43,8
	29 (45%) Without HR	1'236'733	19,2	335'404	18,2
10 (15%) Combined Burning Composting Plants	6 (9%) With HR	498'750	7,8	131'916	7,2
	4 (6%) Without HR	362'000	5,6	96'912	5,3
1 (2%) Compost Plant	1 (2%) Only Compost.	21'000	0,3	5'882	0,3
11 (17%) Controlled Landfills		673'667	10,5	194'564	10,6
64 (100%) total		5'352'870	83,2	1'570'058	85,4
? Uncontrolled Dumps		1'076'530	16,8	269'132	14,6
TOTAL		6'429'400 2)	100,0	1'839'190	100,0

1) HR = Heat recovery

2) Included is the the Principality of Liechtenstein with its population of 24,000

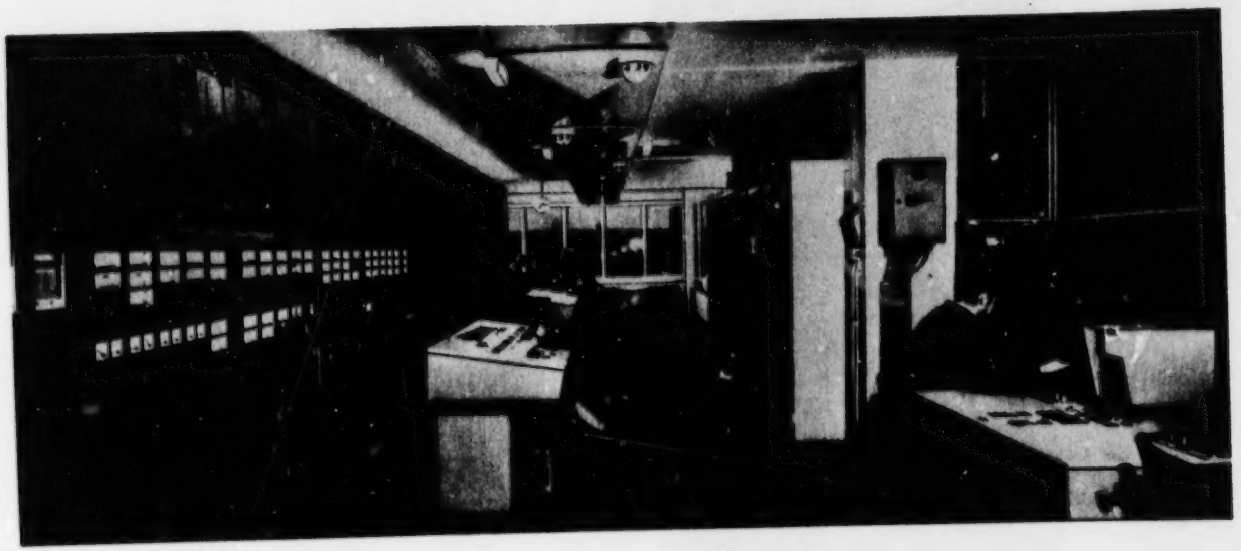


FIGURE 1-5. CONTROL ROOM WITH SCALE OPERATOR, CRANE OPERATOR AND PLANT CONTROL ROOM OPERATOR (COURTESY WIDMER & ERNST-ALBERTI-FONSAR)

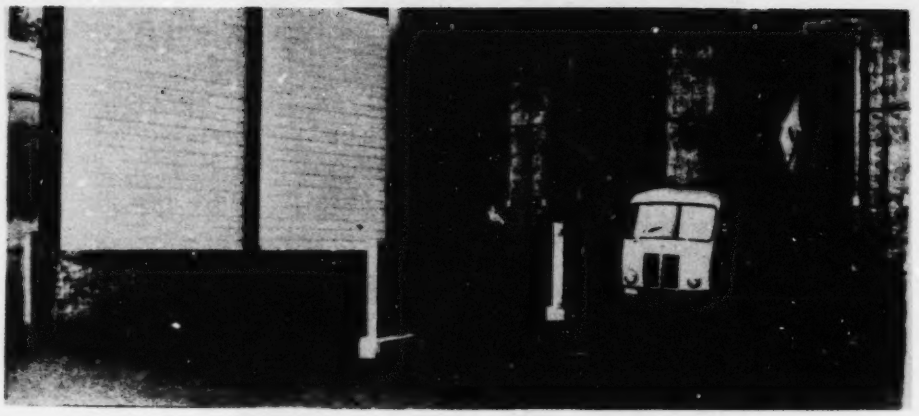


FIGURE 1-6. TRUCK DELIVERING TO REFUSE BUNKER,
(COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

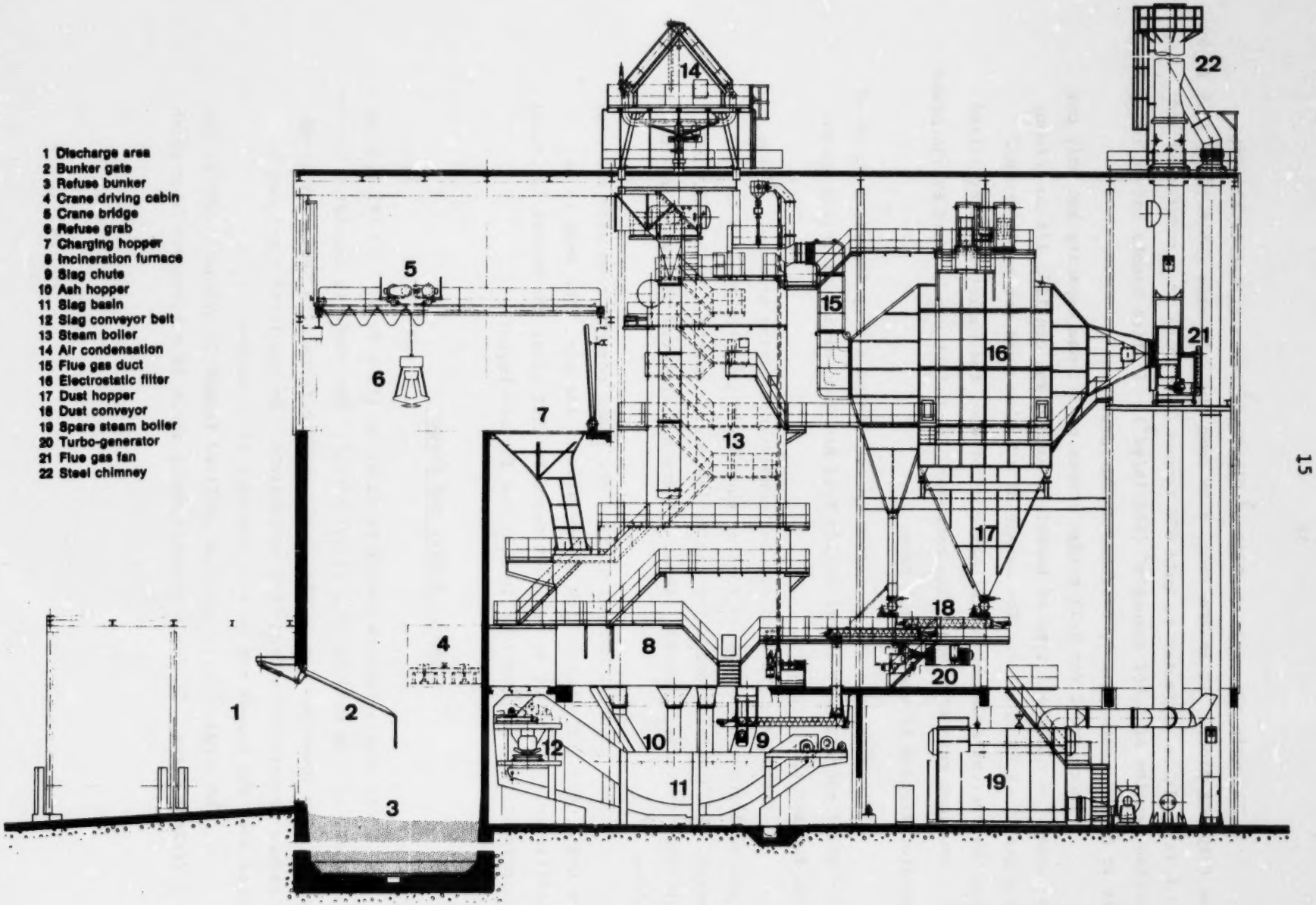


FIGURE 1-7. OVERALL SECTION INSIDE THE WERDENBERG PLANT
(COURTESY WIDMER & ERNST-ALBERTI-FONSAR)

The main plant pit is 1300 m^3 (1690 yd^3) when filled level with the tripping floor. It is 20m long, 8.5m deep and 7.5m wide (65.6 ft by 27.9 ft by 24.6 ft). It is estimated to hold 600 tonnes (545 tons) at a compressed and settled density of 0.462 tonnes/m^3 (645 lb/yd^3). If fire breaks out in the pit it can be controlled by overhead sprinklers.

There are 2 Von Roll bridge cranes of 5 tonne capacity but only one is needed. A clamshell type of bucket on each crane can lift 1/2 to 1 tonne at a grab 2 m3 (2.62 yd^3). The weight of a bucket load can be determined from the current consumed by the cable motor when the bucket is being lifted at a constant rate of speed. The corresponding weight can be read by the crane operator sitting in the control room.

The pit and crane operation is considered a very important facet of good plant operation to assure steady feed and good mixing of refuse which aids furnace operation.

There were problems due to inexperience during startup. If the crane cables were not kept in tension they would jump the pulleys on the bucket. With careful operation the cables last 2 months. With unskilled operation they last 2 weeks. About 2 hours are required to repair broken cables.

This plant is unusual in that the plant control room also contains the crane operator's perch high on one side of the pit. The room is air conditioned. The crane is semi-automatic in that after the bucket is loaded the crane lifts and positions it over the furnace hopper.

Furnace Hopper and Feeder

The single furnace hopper is 4m by 4m (13.1 ft by 13.1 ft) and the feed chute is 2.5m by 1.2m (8.2 ft by 3.9 ft). The chute is insulated but uncooled. The lower portion of the chute near the furnace is low alloy steel to reduce deterioration from high temperature. An insulated cover can be placed over the hopper top to stop burnback if it occurs.

The single-level, ram-type inclined feeder is hydraulically driven by a Vickers drive. It feeds intermittently about 12 strokes per hour which

is about half the frequency of the reciprocating grate sections. The feed is manually controlled from the control room. A spare hydraulic drive is available. No repairs have been needed in 3 years.

Burning Grate

The Alberti-Fonsar GMP-7 stepped grate is in 7 sections which provides an average fuel bed slope of about 24°. It was fabricated in Italy by the Fonderie e'Officine di Saronne S.p.A. using a grate material which is 25-30% chromium, 4% nickel, with some manganese and silicon. Figure 8 shows that the grate is made up of steps which alternately are fixed and reciprocating. The reciprocating parts have a maximum stroke of 380mm (15 in) with the normal stroke being 350mm (14 in) which occurs about once every 2 minutes. As the upper step moves forward it tends to tumble the burning refuse downward to the next step, thus providing gentle agitation. Grate temperature can be monitored by the control room operator from indicators connected to three thermocouples located under the grate, near the middle of the grate surface and on a fixed grate section.

The grate sections were guaranteed for 16 months. No grate parts have been replaced in 3 years. The manufacturer expects the grate to last 5 to 10 years. Some problem has been encountered with pluggage of the air holes in the grate by fused aluminum and plastics. When this happens, workmen wearing heavy wetted asbestos suits enter the partially cooled chamber to remove or punch through the fused material in the grate holes.

Analysis of a sample of the grate residue resulted in a carbon content of 2.21 percent. This residue is dropped when hot from the end of the grate into a large concrete quench tank which appears as a shallow slag basin in the lower part of Figure 7. At the deepest point, the water in the basin is 1.7 m (5.57 ft) deep. Residues from the precipitator and boiler passes are also dropped into this tank. The quenched residue settles to the bottom of the tank from which it is removed continuously by a 12 m (39 ft) drag-chain conveyor which, in turn, discharges the wet material to two rubber belt conveyors in series which deliver it to a three sided waste area on the ground floor.

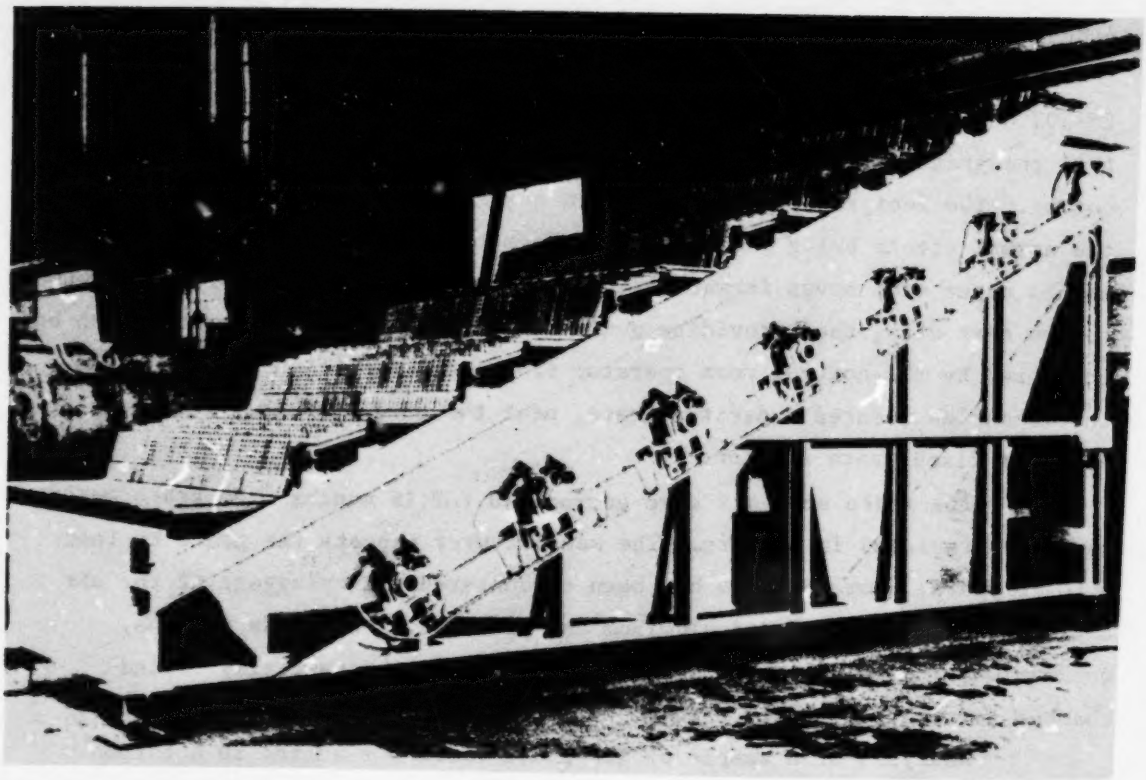


FIGURE 1-8. AN EXAMPLE OF THE ALBERTI-FONSAR STEP GRATE SYSTEM ASSEMBLED AT THE FACTORY (Courtesy of Widmer * Ernst - Alberti-Fonsar)

The manufacturer believes that they have since evolved a much better quench-tank removal device involving a piston-driven swing gate which tends to compress the residue as it lifts it much more nearly vertically out of a much smaller, curved-bottom steel tank. As a result, the discharged residue is said to have only 28 percent moisture as against 40 percent from the system at this plant. The newer system also costs less and produces less waste water. The power consumption of the slow chain is low; the two-motor drive totals only 8 kw, but 4 kw is now seen to have been sufficient. However, corrosion of the chain is expected to entail high maintenance. There is no provision to recover scrap metal from the residue.

The wet residue which is discharged by the conveyor to the "ash floor" is lifted by a front-end loader to a truck which carries to approximately 3 km (1.9 mi) to a mountainside quarry. Occasionally the piles are leveled with a scraper. There is no daily cover, no lining to capture leachate and no final cover. The plant is charged only 0.50 S.Fr. ($0.20) per ton of ash residue. This landfill (doponie*) is estimated to last 5 years.

In 1976 this plant burned 26, 191 tonnes (5.5 tons) in 4740 hours of operation, an average rate of 132.6 tonnes/day (146 tons/day).

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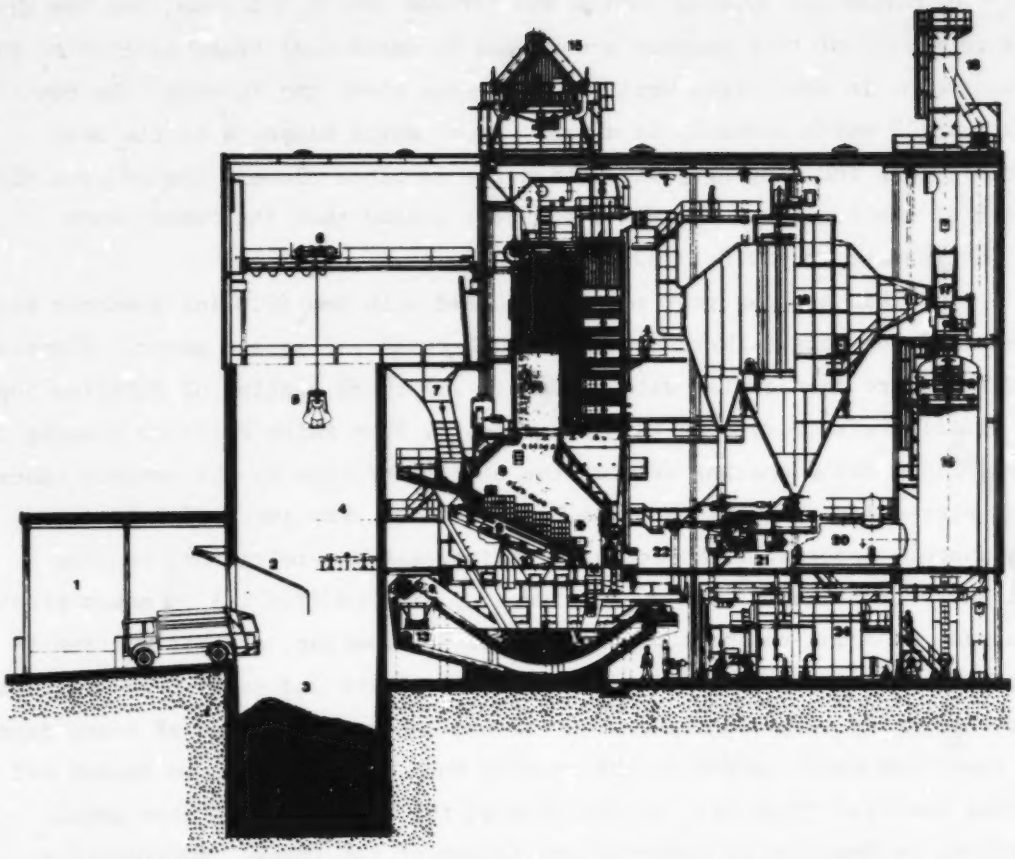
*deponie--French for landfill.

Furnace Wall (Combustion and First Pass Radiation Chambers)

The water-tube walled portion of the furnace, is shown in Figure 9, an open vertical passage approximately 3 m by 3.5 m (10 ft by 12 ft, approximately) in cross section and approximately 11m (35 ft) tall. Its volume is approximately 110 m^3 (3,884 ft^3). It is located directly above the furnace and is intended to provide travel time for final burnout of the furnace gases while allowing for radiant cooling of the gases and their entrained dust load. In this way, partial cooling is achieved without opportunity for obstructional deposition of hot, sticky fly ash. Ash deposition will occur on the water-tube walls but not to the extent that the deposit can become a major resistance to gas flow. These deposits are removed from the water walls by manually scraping every 5,000 hours. At the same time. the convection passes are washed.

The wall tubes are made of #35 carbon steel, 76.1mm (3.0 in) diameter, 4mm (0.16 in) thick, spaced on 78 mm (3.1 in) centers. Thus, the tubes are nearly touching but are not connected together by welded fins as is done in many other modern plants. This tall vertical water-tube wall passage and the main combustion furnace are both covered on the outside with 150 to 250mm (6 to 10 in) thick high temperature insulation consisting primarily of calcium reinforced with asbestos fibers.

The sides of the furnace are composed of two different surfaces. Near to the grate and for about 1.5m (4 ft) above the grate the wall is formed with about 85 air-cooled cast iron blocks made by Kunstler (Zurich) on each side which allow a small amount of cooling air to enter the furnace through small holes in the iron blocks and through narrow air gaps between adjacent blocks. The blocks are about 250mm (10 in) tall and 200mm (8.5 in) wide. Above the cast iron blocks, the furnace wall is formed by Plibrico Super AB plastic refractory 150mm (6 in) thick backed up by 250mm (10 in) high-temperature calcium silicate insulation.



1 Delivery Area
2 Bunker Door
3 Refuse Bunker
4 Crane Pulpit
5 Crane
6 Refuse Grab Bucket
7 Charging Hopper
8 Incinerator Furnace
9 Step Grate
10 Ash Hopper
11 Residue Chute
12 Residue Basin
13 Residue Conveyor Belt
14 Steam Boiler
15 Air Cooled Condenser
16 Electrostatic Precipitator
17 Exhaust Gas Fan
18 Steel Chimney
19 Hot Water Heater
20 Feed Water Tank
21 Turbogenerator
22 Collected Flyash Conveyor
23 Feedwater and Heating Water Pumps
24 Oil-Fired Stand-by Boiler

FIGURE 1-9. SECTION THROUGH WERDENBERG-LIECHTENSTEIN WASTE-TO-ENERGY PLANT, COURTESY WIDMER + ERNST (ALBERTI-FONSAR)

Thus, the lower quarter of the main furnace sidewalls are cooled only by forced air flowing behind and through the wall blocks, but the front and rear wall of that chamber are cooled by water-wall tubes similar to the arrangement in the large, vertical open pass above the furnace. In the "rear wall" which actually is a rear "arch" which slopes a little more steeply than the sloping grate, there are 40 tubes closely spaced over the width of the furnace. The W + E engineer stated that the temperature in the furnace is 950 C (1742 F).

This sloping rear roof is studded with 8mm (0.3 in) diameter studs, 22mm (0.9 in) long. There are about 1000 studs per square meter. These tubes and studs are then coated with a 25mm (1 in) thick coating of Plibrico Super AB plastic refractory. In the newer plants, 40mm thick Plibrico coating is used. This thick coating reduces the heat absorption by the covered tubes but is a protection against corrosion. It has been very successful here and elsewhere. Apparently the decision to increase the refractory coating thickness from 25mm (1 in) as used here up to 40mm (1.6 in) in newer plants was made in order to increase the life of the coating, as this coating is subject to deterioration from cracking as it heats and cools. In addition, the coating is mechanically eroded and spalled by the action of heavy deposits of fused ash which adhere to the coating then break off or are broken off during periodic cleaning. As portions of the coating are broken away, patching is required to maintain protection of the tubes. Apparently a thicker coating reduces the frequency of patching required.

Welded studs and refractory coating are also utilized over the entire lower half of the vertical, water-tube walled boiler pass immediately above the furnace. This very common design of coating was applied after corrosion was experienced in 1970 in a similar furnace at Baden-Brugg, which required protection after only 2000-3000 hours operation.

The steam generating surface of the boiler is stated by the manufacturer to be 835 m^2 (8988 ft^2).

Second Boiler Pass

When the upward-flowing gases reach the top of the first water-tube walled gas passage they then are turned horizontally into the entrance of a second water-tube walled vertical pass (see Figure 9) in which the gases are further cooled as they flow downward. These water tubes have no studs nor coating as by this time the gases are cooled to about 650C (1203F) and corrosion and erosion are thus no threat to water tubes.

Superheater

The partially cooled gases leaving the bottom of the second open boiler pass then make a 180° turn and, flowing upward, enter the first bank of horizontal steam tubes of the 2-section superheater. Final steam temperature control is achieved by a spray-type attemperator between the 2 superheater sections.

In each row of superheater tubes there are 32 tubes. Each tube has a 33.7mm (1.33 in) diameter and a wall thickness of 4mm (0.16 in). The tube material in the first section is 14% chromium, 3% molybdenum and in the second section 0.14% plain carbon steel. The spacing of the tubes horizontally and vertically is 100mm on centers. The gas flow pattern is straight upward through the bank as the tubes are in line and not staggered. The design temperature for the gas entering the first superheater section is 650C (1203F). The temperature leaving the second section is 520C (968F).

A single cascade of falling steel shot once an hour cleans the economizer and superheater. The top row of superheater tubes is protected by steel shields from the impact of the falling shot. Every 5,000 hours the economizer and superheater are cleaned by washing by a German company that specializes in boiler cleaning.

In future designs the manufacturer favors more gas space between the superheater tubes. They also believe that shot cleaning is preferable to soot blowing.

The manufacturer expects that the first (bottom) row of superheater tubes may need replacement every 10,000 to 11,000 hours owing to erosion or corrosion or a combination of both.

Boiler (Convection Section)

The water tube boiler is a natural circulation type built by Alberti-Fonsar under the Eckrohr Kessel patents of Dr. Vorkauf of Berlin. Steam capacity is 12 tonne per hour (26,460 lb/hr) with peak capacity to 16 tonnes per hour (35,275 lb/hr) at 40 bar (566 psia) [390 KPA] and 395C (743F). The overall height of the boiler is approximately 18m (59 ft). Its width is 3.7m (12 ft) and its depth from the front water wall to the rear of the convection sections is approximately 6.2m (20.3 ft).

Temperatures are measured continuously for feedwater temperature, economizer water outlet temperature and saturated and superheated steam temperatures. These are all recorded on strip charts in the control room.

Boiler control is automatic from steam pressure but can be overridden by a control element that senses overheating of the gases leaving the furnace.

The responsible boiler operator must have a certificate of the Federal Boiler Association which normally can be obtained after 1 year experience plus part time schooling.

Reliability of this relatively new plant was stated to be 100 percent except for scheduled shutdowns. No major repairs have yet been required and at least 20 year life is expected. Amortization period of 20 years is common in Switzerland.

In 1974-75, the new plant was operated at an excessive rate for only 3 or 4 days per week. The remainder of the excessive demand time, steam was supplied by the oil-fired standby boiler. Design heat input is 14×10^6 kcal/hr (55×10^6 Btu/hr)[58.5×10^9 J/hr]. However, the actual input ranged up to $17\text{-}18 \times 10^6$ kcal/hr (71.4×10^6 Btu/hr)[75.3×10^9 J/hr] amounting to a 20% to 29% overload. Formal warning to the owner by the manufacturer of the possible deleterious consequences of such overloading led to subsequent operation at more nearly normal loading. At the time of our visit, May 2-4, 1977, there appeared to have been no permanent damage resulting from the period of overloading. However, at the end of the first 11,000 hours of operation the first row (bottom) of horizontal superheater tubes had to be replaced because of erosion. This could very well have been a direct result of overfiring the system.

On April 1, 1977 the Swiss organization of pressure vessel inspectors issued a report on their inspection of this boiler. They reported the boiler in good condition with some dirty surfaces but no unusual tube wastage. Some steel supports in the superheater section showed some corrosion.

The manufacturer feels that the trend will be toward horizontal configuration of vertical tubes in the convection section with periodic rapping to remove ash deposits. To minimize danger of tube metal fatigue the amplitude of rapping would be 0.5mm (0.02 in) with emphasis on rapid acceleration by the rapper rather than on amplitude to dislodge the deposits.

Economizer

The economizer, see Figure 9 is located near the top of the boiler in this third pass and consists of vertical carbon steel tubes providing a heating surface of $165m^2$ ($1,775\ ft^2$). The 2 economizer sections are approximately 2.6mm high, 0.9m deep and 3.2m wide (8.5 ft by 3 ft by 10ft). So far the economizer has required no maintenance. Cleaning is achieved by the gravity fall of a shower of steel shot which intermittently is delivered to a distributor at the top of the economizer from which it falls by gravity through the gas passages in the economizer and in the superheater. The falling steel shot cleans deposited ash from the tubes and carries it down to an ash separation system where it is removed from the shot and is transported to be mixed in with the grate residue. The cleaned shot is then conveyed pneumatically to the top of the economizer to repeat the cycle. The shot cleaning process operates about 4 minutes every hour.

Boiler Water Treatment

Feedwater is treated by ion exchange plus hydrazine to the following specifications:

ph 7-8.5 (measured continuously)
Hydrazine <0.25 mg/liter
SiO_2 <0.3 mg/liter
Conductivity >0.08 megohms (measured continuously)
Fe <0.05 mg/liter
Cu <0.01 mg/liter
Hardness <0.01 milli equivalent/liter.

Primary (Underfire) Air Supply

The combustion air to the grate is supplied by one BSH* blower rated at 170 mm (6.7 in)WC static pressure, 194 mm (7.6 in)WC total pressure. This air supply is taken from the refuse bunker area and is divided into three approximately equal grate zones, each controlled by a manually set damper adjustable from the control room. At the plant owner's request, provisions were included to measure air flow and pressure to each zone. The rated blower capacity is 32,000 m^3/hr (18,816 cfm).

Other than minor startup problems caused by the motor-blower coupling, there have been no maintenance problems. The manufacturer anticipates that in very dusty plants, blade deposits may induce unbalance and vibrations which could require annual bearing replacement. In 3 years of operation, this has not happened in this very clean plant. At earlier plants, such unbalancing dust deposits were eliminated by changing fan blade shape to a less efficient design which dropped blower efficiency from about 79 or 80 percent to 75 percent.

Secondary (Overfire) Air Supply

The overfire air supply is also taken from the bunker area. Blower capacity is 13,500 m^3/hr (7940 cfm) at 20 C (68 F), at a static pressure of 350mm (13.8 in), total pressure of 385mm (15 in).

As is shown in Figure 10 and diagramatically in Figure 11, there are two sets of overfire jets in each sidewall. The upper row of six jets on each side consists of 60mm (2.36 in) diameter jets in a horizontal row about 5 m (16.4 ft) above the grate to provide air and turbulent mixing where the burning gases pass upward from the top of the furnace combustion chamber to the first open boiler pass. The lower row of 12 jets on each sidewall are about 1.8m (5.9 ft) above the grate and along an inclined line parallel to the grate. The air flow to the jets is modulated automatically according to furnace outlet temperature by a motor operated valve. A high temperature calls for more air to dilute and thus cool the gases.

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* BSH = Buttner-Schilde-Haas

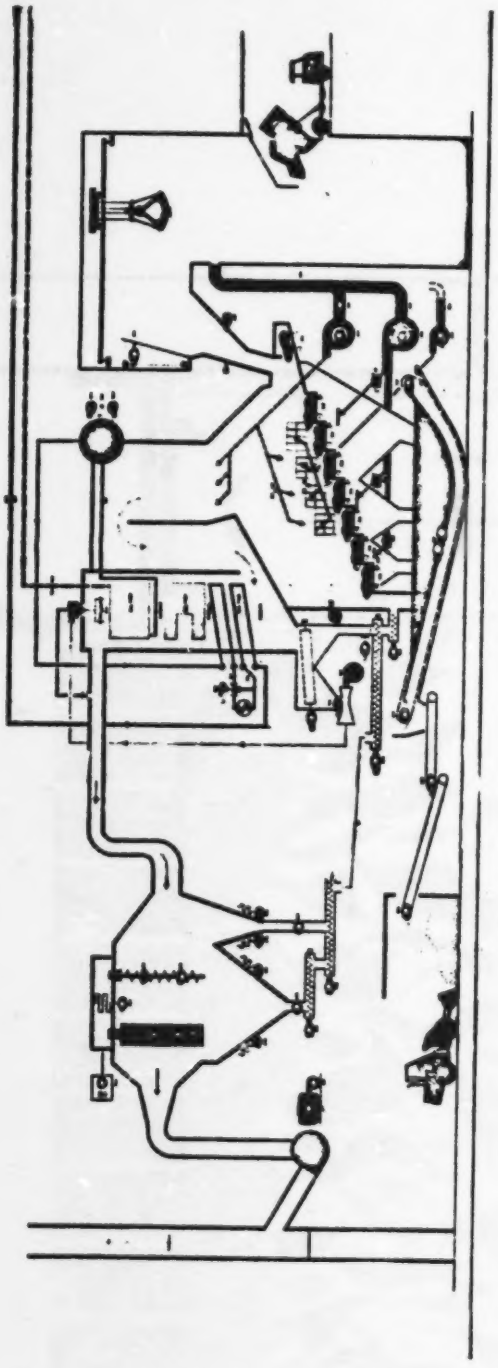


FIGURE 1-10. SCHEMATIC VIEW OF WERDENBERG-LIECHTENSTEIN WASTE-TO-ENERGY PLANT, (COURTESY OF WIDMER & ERNST-ALBERTI-FANSAR)

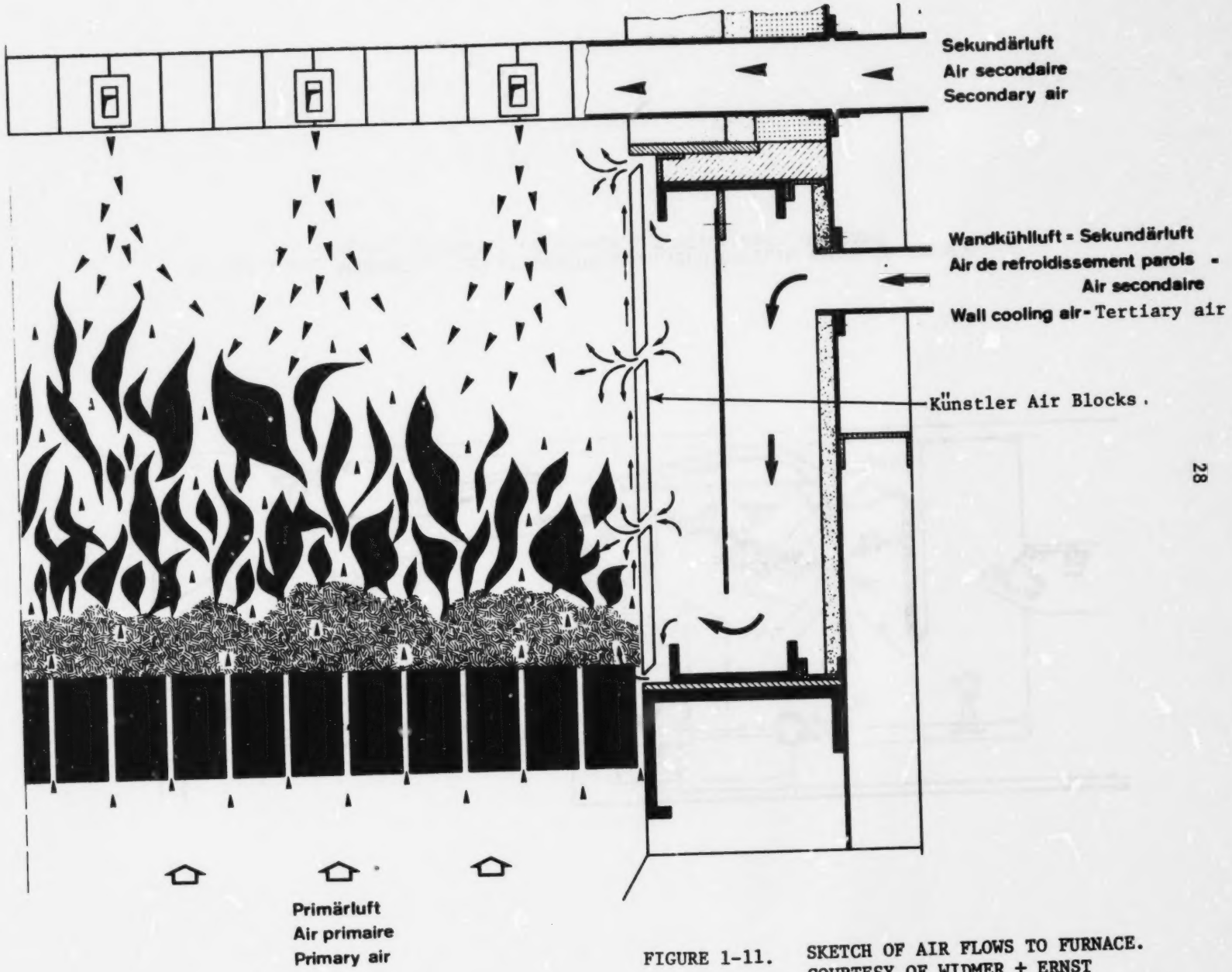


FIGURE 1-11. SKETCH OF AIR FLOWS TO FURNACE. COURTESY OF WIDMER + ERNST

The manufacturer states that they prefer front and top (or rear) wall jets over this sidewall jet arrangement and their future designs will not use sidewall jets. The advantages seen for frontwall jets are:

- Better mixing
- Better air distribution in the furnace
- Shorter flame length
- Less carbon monoxide.

Tertiary (Sidewall) Air Supply

In addition to the overfire air, tertiary air is supplied near the grate through Künstler cast iron blocks in both sidewalls as shown schematically in Figure 11. This air serves both to cool the cast iron blocks and to provide an upward flowing layer of combustion air along the sidewalls for any rich gases that may be burning there. The air comes not from the bunker but from the furnace room. The forced air is supplied to the back or "outside" of the blocks and flows in a generally downward direction behind a steel baffle and then upward until it finds its way into the furnace through the gaps around the periphery of each block. A constant flow of tertiary air is supplied to the blocks by a separately unmodulated blower rated at 12,900m^3/hr (7600 cfm) at 20 C at a static pressure of 180mm (7.1 in)WC, total pressure of 190mm (7.5 in)WC. The 85 cast iron wall blocks on each sidewall are made of 27-30 percent chromium, 0.53 percent nickel, with small amounts of titanium and molybdenum.

An alarm is sounded in the control room if the temperature of a thermocouple on one of the blocks exceeds a set value of (300 C) (527 F). This temperature and that of the steel structure nearby to the plate are both recorded in the control room. At this small plant, no wall blocks have been replaced during the 3 years of operation. Some abrasion of the blocks has been noted where the burning refuse slides along the blocks. So far, the eroded area appears to have lost 1 to 3mm of iron.

It can be seen that the total capacity of secondary plus tertiary air is 26,400 m^3/hr, nearly as great as the 32,000 m^3/hr available as primary air. However, not all of this capacity is used. The operator is instructed to regulate the overfire air supply to maintain a furnace exit

CO_2 of about 9 or 10 percent. This is in the range of 120 percent excess air. From a heat recovery standpoint, it would be desirable to have the excess air much less but this manufacturer's experience apparently is that the higher temperatures associated with lower excess air causes metal wastage problems.

The induced draft fan has caused some concern because of vibrations caused either by the belt drive or by resonance in the duct system. It has not been worsening. In other plants, this is sometimes caused by buildup of fly ash on the fan blades. The fan is inspected once in month but has required no maintenance except possibly replacement of a drive belt.

Heat Release Rate

This plant is conservatively designed from the standpoint of grate size, furnace size and boiler size. This can be judged from the following tabulation of heat release rates:

Combustion rate	120 tonnes/day 5 tonnes/hr 5.115 tons/hr 5,000 kg/hr 11,023 lb/hr
Grate Area (sloped)	$17.5m^2$ (2.5 x 7.0) $188.4\ ft^2$
Grate burning rate	$285.7\ Kg/m^2$-hr $58.611b/ft^2$-hr
At an average LHV of	2800 Kcal/kg
the total heat released is	14×10^6 Kcal/hr
with grate release rates equivalent to	$800,000\ Kcal/m^2$-hr
or	$295,000\ Btu/ft^2$-hr
Furnace heat release rate considering only the volume from the grate up to the entrance to the silicon-carbide coated water-tube-walled first pass: volume	$115.65m^3$ $4084\ ft^3$ $121,055\ Kcal/m^3$-hr $13,603\ Btu/ft^3$-hr
If the SIC refractory lined water-tube-walled volume of the first pass is included as part of the burning volume, an additional $26.4m^3$, total the heat release rate is	$142m^3$ $5014\ ft^3$ $98,591\ Kcal/m^3$-hr $11,080\ Btu/ft^3$-hr

These are all low heat release rates.

Energy Utilization Equipment

This small 120 ton per day plant produces the most complex assortment of energy forms, considering the plant size, that the researchers have seen in their travels. Most of these forms can be understood by reviewing Figure 12. These seven forms and uses are listed in order of energy magnitude.

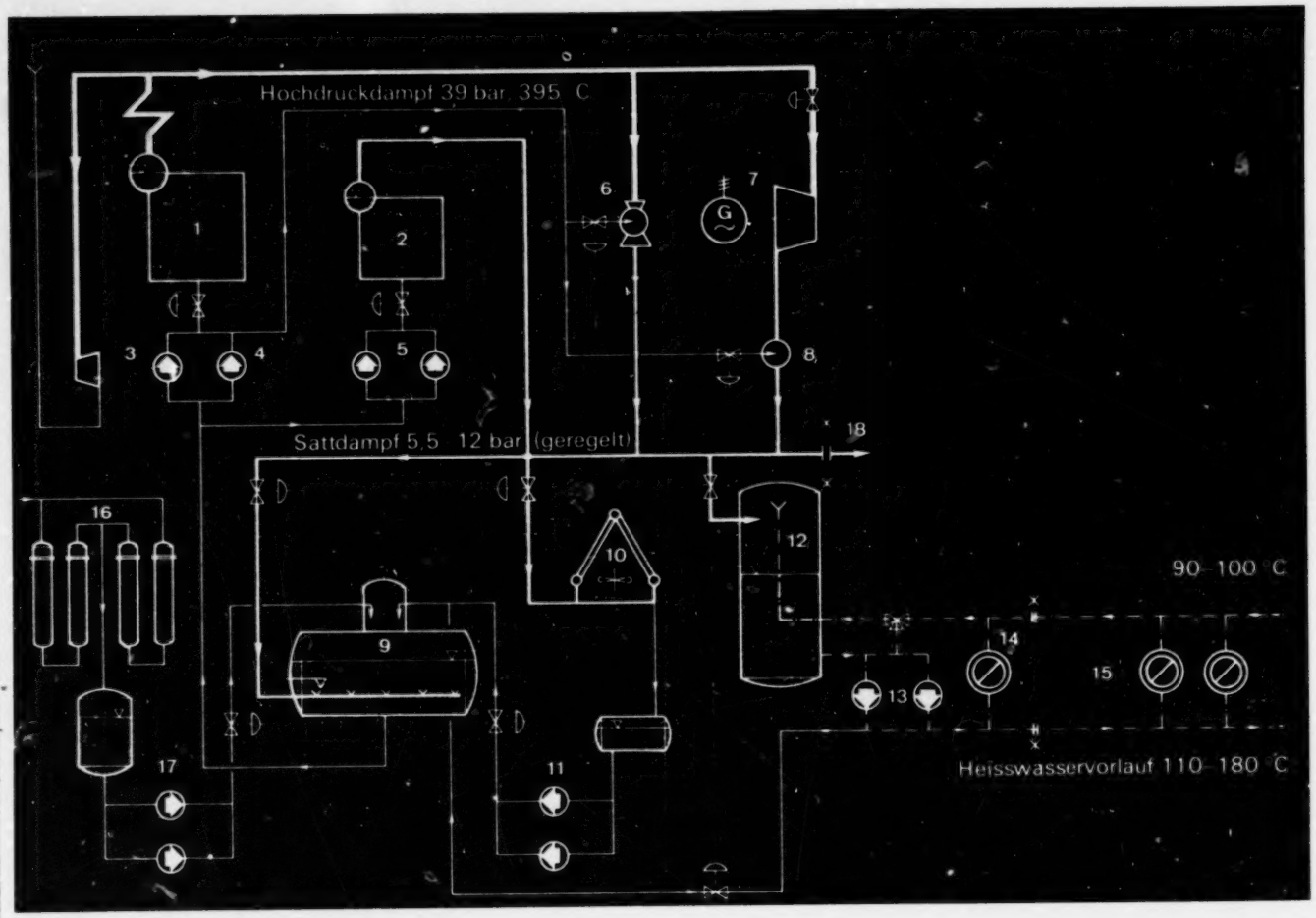
- Hot water for district heating
- Steam for industrial process
- Electricity for the community
- Electricity for internal use
- Steam wasted on the roof
- Steam for internal use
- Hot water for internal use

When more energy is needed than the RFSG can produce, the auxiliary standby steam boiler shown in Figure 13 can be used.

A back-pressure steam turbine-generator, shown in Figure 14 is used to produce two energy forms: electricity and medium quality steam. A small back-pressure turbo-generator has a maximum electricity generating capacity of 0.85 mw at 10 kv. Inlet pressure is 39 bar (551 psig) [8.2×10^6 Pa] and temperature is 395 C (741 F). Outlet pressure is 6 bar (72.5 psig) [1.05×10^6 Pa] and temperature is 250 C (482 F). The back pressure varies between 5.5 and 12 bar. Excess steam is condensed in a forced draft air-cooled, roof-top condenser as shown in Figure 15.

The 250 C, 6 bar exhaust steam from the turbine is cooled to 160 C, 6 bar by direct water spray and is then piped to a nearby chemical plant which returns the condensate at 5 bar with little loss. Figure 16 Shows the steam distribution and condensate return tunnel.

Hot water for district heating is produced in a steam-to-hot water heat exchanger as shown in Figure 17. Hot water at 6 bar (85 psia) and a temperature of 110-150 C (230-302 F) is delivered to the chemical plant and also to an apartment complex involving 300 units. Figures 18 and 19 show the district heating system under construction, the distribution pattern and the hot water distribution and return time and the apartment building.



1. Refuse-fired steam generator
2. Oil-fired boiler
3. High-pressure feedwater turbo-pump
4. High-pressure feedwater motorized pump
5. Mid-pressure feedwater motorized pump
6. Turbine steam by-pass
7. Synchronons turbogenerator, 950 Kva
8. Steam temperatur regulator
9. Feedwater tank and deaerator
10. Air-cooled condenser
11. Condensate pump
12. Steam-to-water cascade
13. Hot water district heating pump
14. Heat exchange for plant heating
15. District heating system
16. Feedwater treatment facility
17. Makeup water tank and pumps
18. Industry steam supply line

FIGURE 1-12. WERDENBERG STEAM AND HOT-WATER DISTRIBUTION SYSTEM (COURTESY WIDMER & ERNST, ALBERTI-FONSAR)

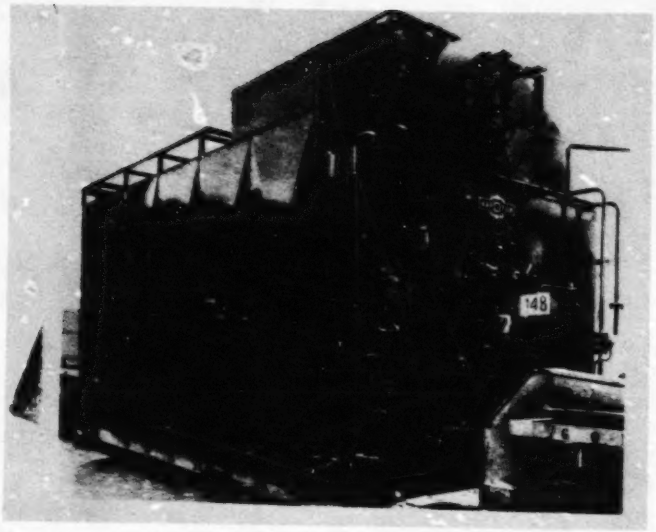


FIGURE 1-13. OIL-FIRED STANDBY BOILER ON TRANSPORT TRUCK
(COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

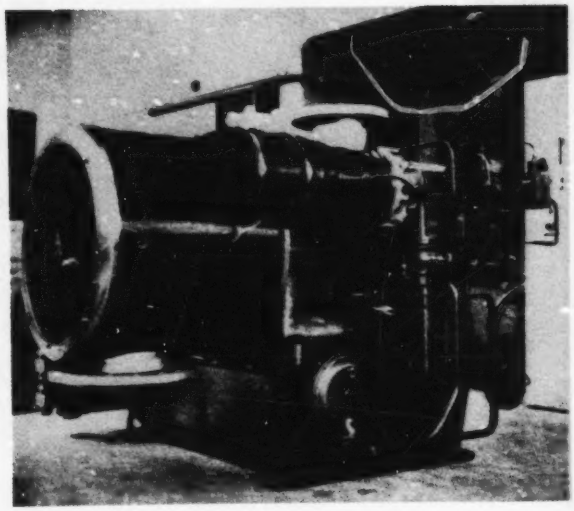


FIGURE 1-14. STEAM TURBO-GENERATOR (COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

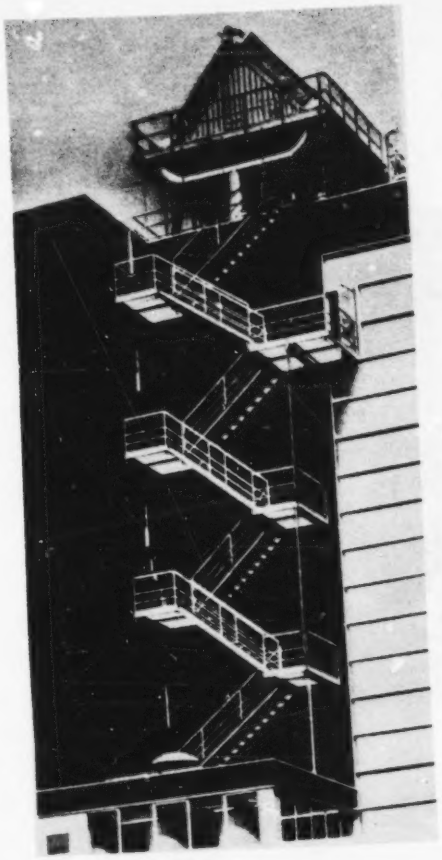


FIGURE 1-15. TWO VIEWS OF AIR-COOLED CONDENSER AT WERDENBERG (COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

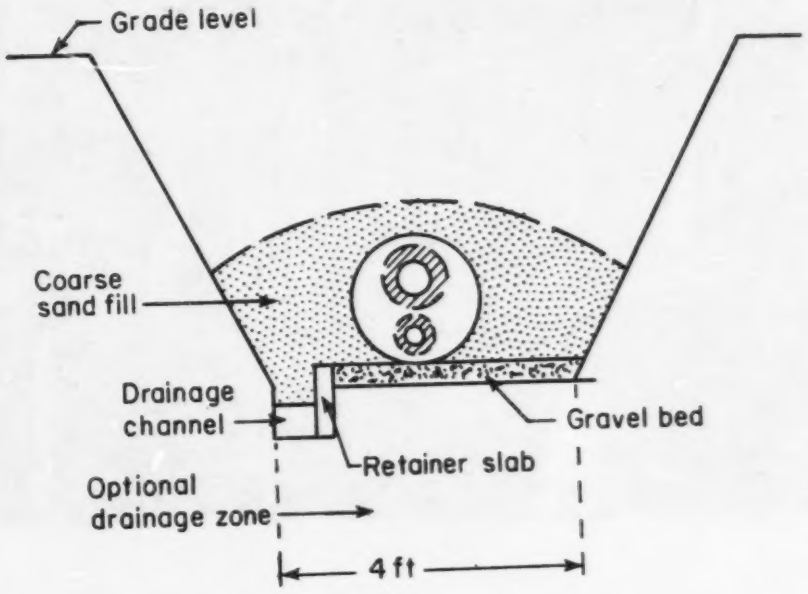


FIGURE 1-16. STEAM AND HOT WATER DISTRIBUTION TRENCH AT WERDENBERG (COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

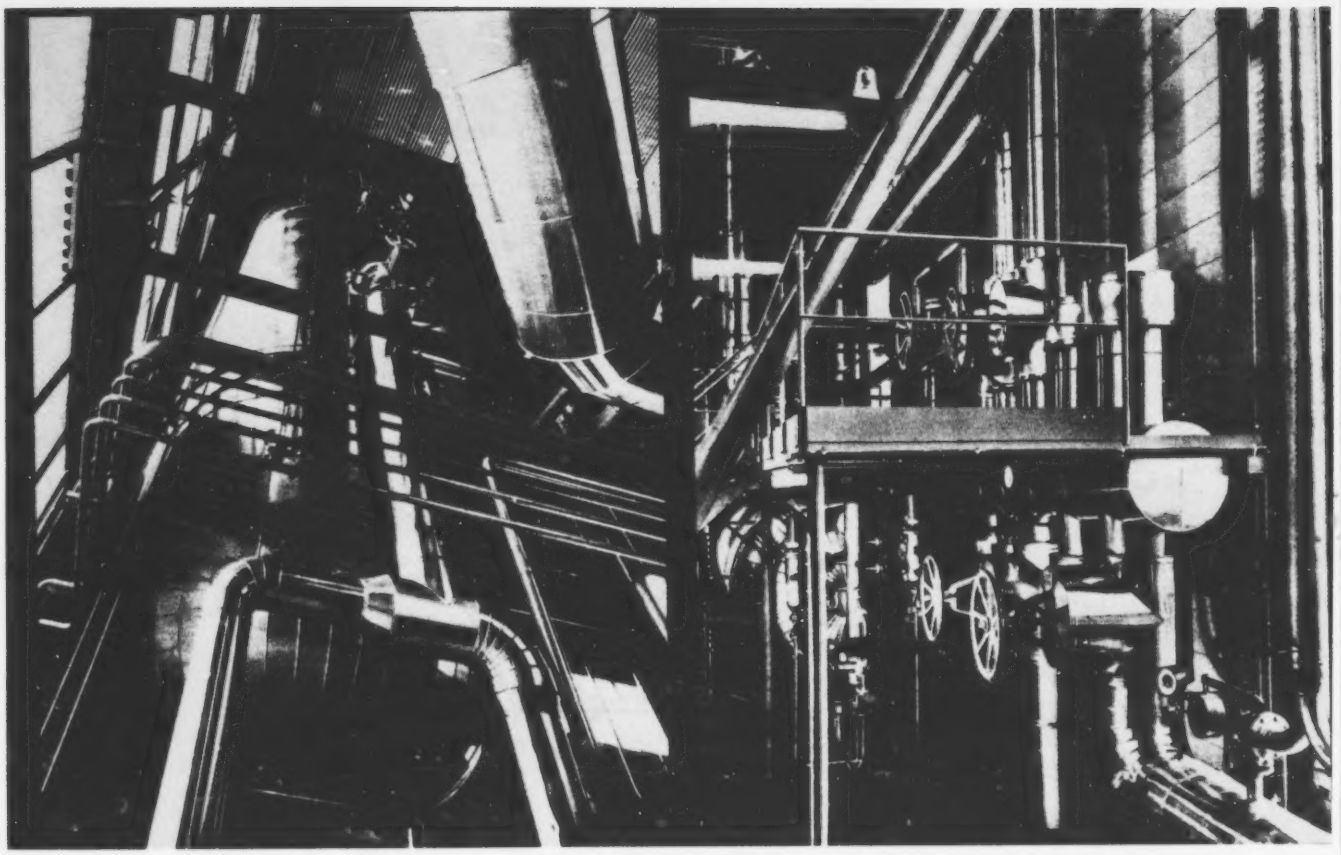


FIGURE 1-17. CASCADE TYPE WATER HEATER ON LEFT, FEEDWATER TANK AND STEAM LINES ON RIGHT AT WERDENBERG (COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

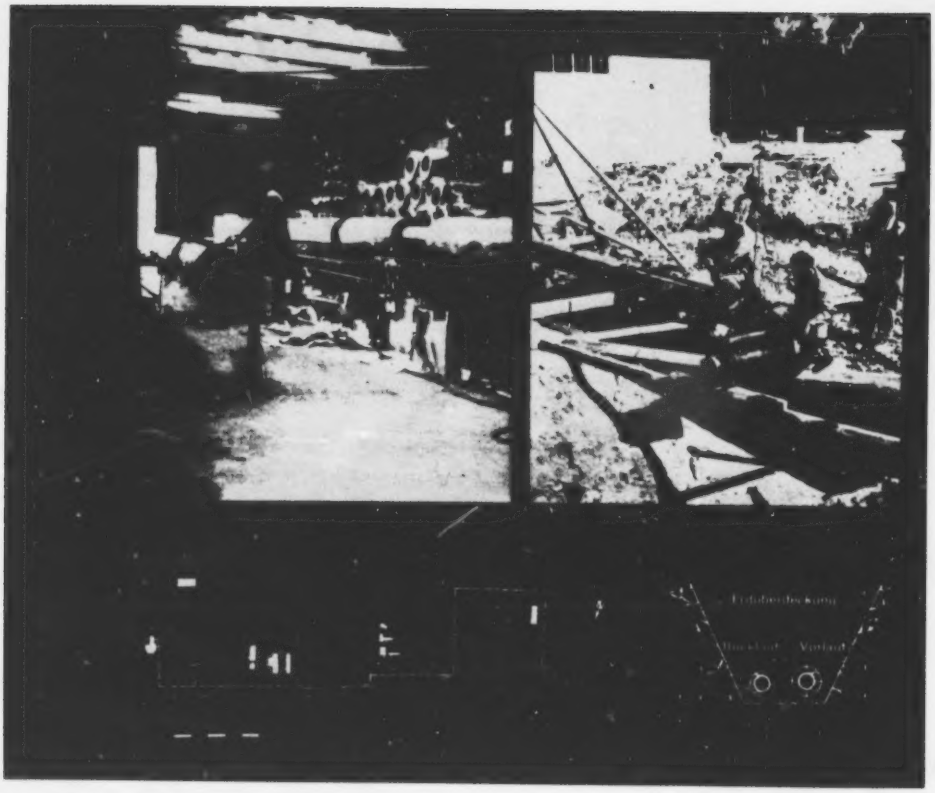


FIGURE 1-18. INSULATION, INSTALLATION AND MAP OF HOT WATER DISTRIBUTION SYSTEM AT WERDENBERG (Courtesy of Buchswerdenberg Society for Waste Management)

FIGURE 1-19. APARTMENT HOUSE AT WERDENBERG HEATED BY HOT WATER FROM STEAM PLANT (COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

The total length of the distribution system is 2-1/2 km (1.5 mi). An additional 0.8 km (0.5 mi) pipeline will be added to provide heat for the railroad station. Other buildings may be included. Where the hot water is utilized for comfort heating, each building has a water-to-water heat exchanger to provide 80 C (176 F) water for the building heating system.

POLLUTION CONTROL EQUIPMENT

During our 3-day visit to the plant, there was no visible plume most of the time and even when visible, it was only barely so against a very clean sky. The sole pollution control at this small plant is a single-field electrostatic precipitator by Elex. Without the hopper it is 9.3 m high, 5.7 m wide, and 5.9 m deep. It has a flow rate of 83,000 m^3/hr at 274 C. Average velocity is 0.67 m/sec (2.2 ft/sec). The gas composition and dewpoint at the precipitator during the compliance test was:

- CO_2 - 5.4 percent
- H_2O - 13.5 percent
- Dewpoint - 51 C (124 F).

Particulates are now limited to 100 mg/Nm^3 (0.0438 grains/ft^3) corrected to 7% CO_2. When this plant was designed, the allowable limit was 150 mg/Nm^3. When tested, it achieved 88 mg/Nm^3 (0.038 grains/ft^3) corrected to 7% CO_2. Bypassing of precipitators has not been permitted since 1972.

In Switzerland, waste-burning plants are limited to gaseous emissions of:

- SO_2 - 300 mg/Nm^3
- HCl - 500 mg/Nm^3.

The precipitator and its duct configuration were tested beforehand by Elex in a small water model to assure a uniform flow pattern. To distribute the gas flow ahead of the charging section, there are three perforated plates in series containing 5 cm holes. The spacing of the collector plates is about 300 mm (11.8 in) providing 17 parallel flow passages. Residence time is 5.9 sec. Total plate area is 1,142 m^2 (12,288 ft^2) with a projected area of 952 m^2 (10,243 ft^3). The plates are cleaned intermittently by a bottom rapper. The charging electrodes are cleaned by a rapper at the top.

Power consumption is 29 kw at 380 volts. Output capacity is 47.5 KVA at 78,000 volts and 600 ma.

The fly ash hoppers are approximately 50 degree inverted pyramids electrically heated and covered with 10 cm (4 in.) of insulation. The collected ash is removed continuously by screw conveyors which discharge into the main residue quench tank.

The precipitator was guaranteed to achieve 97.5 percent efficiency and to emit no more than 100 mg/Nm^3, wet gas corrected to 7 percent CO_2. It achieved better than that: 88 mg/Nm^3, wet at 7 percent CO_2.

So far, the precipitator has needed no repairs. It is cleaned once per year when the boiler is cleaned. For personnel protection, the access doors cannot be opened before an 8-multiple key sequence is processed.

To achieve even lower particulate emissions from future plants, the manufacturer is considering the use of two-field precipitators.

Wastewater Discharge

The wastewater rate from the residue quench tank is about 200 liters/hr (0.9 gpm). System blowdown rate is 160 liters/hr (0.7 gpm). The liquid discharge from the feedwater treatment system is neutralized before discharge. All of these waste liquids plus washroom wastes go to the adjacent sewage treatment plant.

Stack Construction

At the customer's request, the 1.3 m dia (4.3 ft) insulated steel stack is only 40 m (131 ft) tall, 12 m (39.4 ft) above the plant roof. Most of the steel stack is carbon steel. The top 4 meters (13.1 ft) and the bottom 0.5 meters (1.6 ft) are stainless steel. It was fabricated by Lufttechnik + Metallbau, subsidiary of Widmer + Ernst. Flue gases from the oil-fired stand-by boiler are fed into the stack just above the roof. At roof-level, a continuous opacity meter manufactured by Durug (Hamburg) measures flue gas opacity which is recorded in the control room.

POLLUTION CONTROL ASSESSMENT

Although the overall appearance of Swiss cities and countryside is immaculate, this low environmental pollution level is achieved by a minimum of necessary regulation. New regulations are implemented with cautious deliberation. On the other hand, old regulations are tightened where economically and technologically feasible. For example, in recent years, the particulate emission limit to the atmosphere of 150 mg/Nm^3 corrected to 7 percent CO_2 has been dropped to 100. This is equivalent to 0.0438 gr/scf or 0.083 lb per 1,000 lb gas. For 5,000 Btu/lb refuse (2778 Kcal/kg) this amounts to about 0.18 lb/10^6 Btu input (320 g/10^6 Kcal) [76.4 g/GJ].

Similarly, a Swiss survey of municipal refuse shows that 50 percent of the refuse averages about 6 kg/tonne of HCl and that 95 percent of the refuse burned has less than 15 kg/tonne. Potentially, this higher value could result in about 1,700 mg/Nm^3 (1.4 lb/1000 lb) being discharged to the atmosphere. Actually, an unknown amount will stay in the furnace, precipitator, and residue so probably less than 1,000 mg/Nm^3 (0.8 lb/1000 lb gas) is emitted. The fact that scrubbers to remove HCl from the hot gases have not been well developed and no deleterious atmospheric concentrations of HCl have been observed leads the government to caution in regulation of this emission. On the other hand, since HCl emissions are obviously undesirable, there has been a 3-4 year effort to encourage the substitution of innocuous plastics for PVC in the Swiss economy. This still leaves the normal sodium chloride in refuse which constitutes about half of the total amount of chlorine in refuse.

If eventually scrubbers to remove HCl become necessary, the regulatory staff is well aware of their disadvantages:

- Scrubber sludge
- Additional cost
- Corrosion
- Visible wet plume
- Acid wastewater
- Efficiency on fine particulates often low.

Hence, the Swiss concensus is not to require scrubbers unless HCl removal is proven highly necessary. Meanwhile, the PVC content of municipal refuse is being monitored and each plant will be tested for HCl emission about every 2 years.

Noises

This plant, along the inland canal is surrounded by industry and cultivated fields, is remote from human habitations and noise has been no problem. According to Swiss regulations, no plant can emit at its boundary noise exceeding:

- 55 db (A) at night
- 65 db (A) in the day
- 75 db (A) peaks.

PERSONNEL AND MANAGEMENT

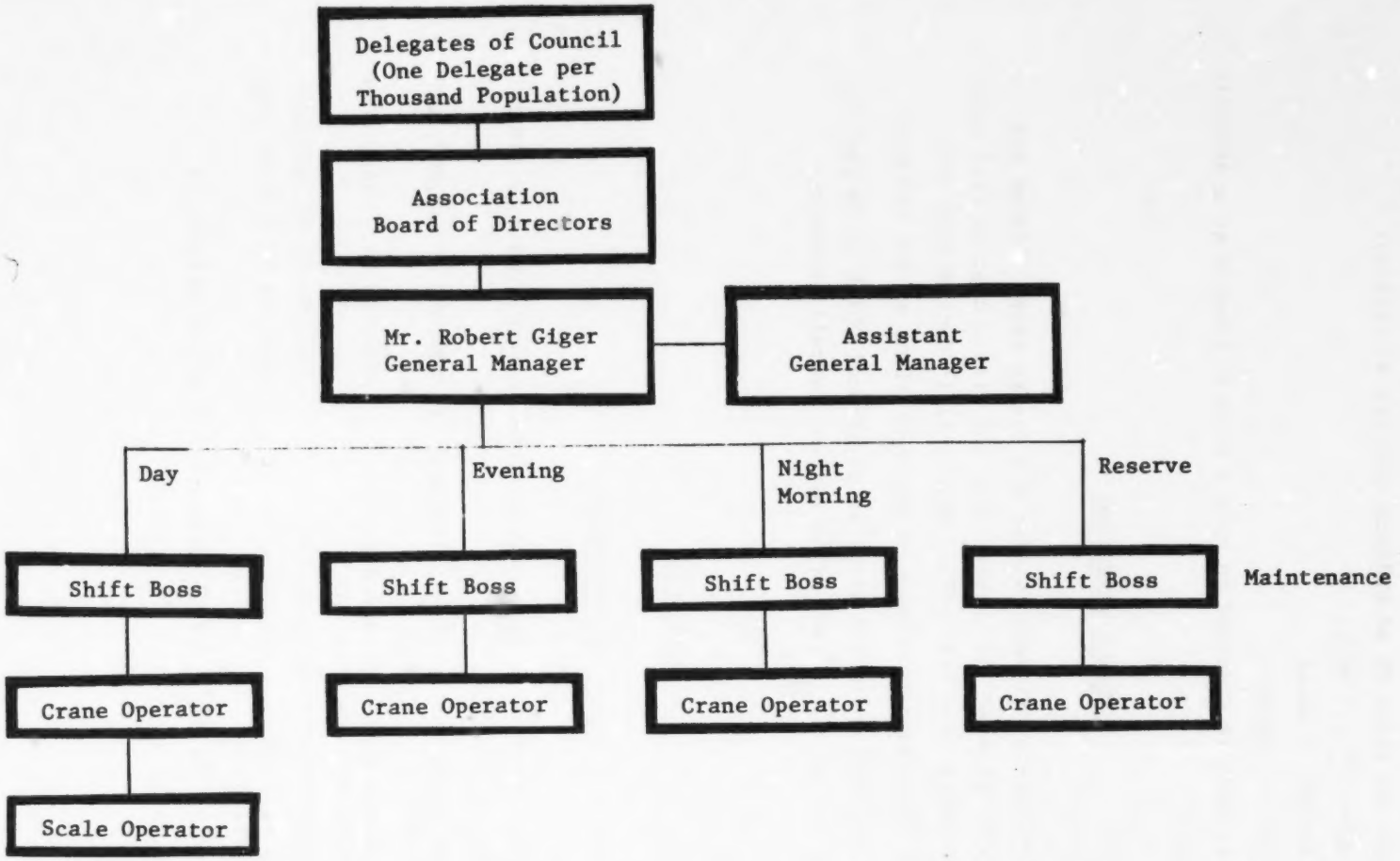
Seventy six (76) delegates are chosen (one for each 1000 inhabitants) to represent them on the Verein fur Abfallbeseitigung (Society for Refuse) Management). These 76 delegates elect an operating Board of Directors. The Board of Directors hires the Plant Manager, who in turn, hires the remainder of the staff.

This plant operates 5 days per week with only two operators on each of four shifts plus a weigh-scale operator in the day shift and the Plant Manager, Robert Giger and his assistant. In addition to the refuse fired steam generator building activity, the two managers are responsible for the compost plant and the separate Incinerator I - now the community's pathological incinerator.

Figure 11 shows the organization for the RFSG only. During weekends, when only the standby oil boiler is fired, one of the shift bosses must be ready to respond to an automatic alarm in his home. In other words, the plant produces hot water, steam, and electricity continuously on weekends - but with no personnel routinely on duty.

Approximate monthly take-home pay is as follows:

- General Manager - 3500 SwFr ($1400)
- Shift Boss - 2600 SwFr ($1040)
- Crane Operator - 2500 SwFr ($1000).
- Scale operator - 2200 SwFr



Shift Boss

1. Controls plant
2. Drives furnace
3. Water analysis
4. Control room
5. Equipment inspections
6. Repairs (minor)

Crane Operator

1. Drives crane
2. Substitute Scale Operator
3. Substitute Control Room

Reserve

1. Vacation replacement
2. Major repairs
3. Shift boss replacement
4. Crane operator replacement

FIGURE 1-20. ORGANIZATION CHART FOR OPERATION OF WERDENBERG PLANT

Vacations are given in accordance with age as follows:

- Age under 45 - 3 weeks
- Age 45-50 - 4 weeks
- Age 50+ - 5 weeks.

The shift boss is expected to have a Federal license as a mechanic or electromechanic.

ENERGY MARKETING

The plant General Manager handles all energy sales. Steam and hot water prices are set so as to compete with the rising cost of fuel oil. At the time of our visit (May 2-3, 1977), No. 2 oil in Switzerland cost approximately 0.30 SF/liter ($0.45/gal) or the equivalent of 375 SF/tonne ($167.91/ton). The plant sells hot water at 20 SF/Gcal which is 56 percent of the cost of No. 2 fuel oil burned at 90 percent overall efficiency.

ECONOMICS

Capital Investment

The capital investment expenditures were available only in gross form as shown below:

- Refuse fired generator building and contents — 13,000,000 SF ($5,200,000)
- Office and workshop-separate building and contents — 1,000,000 SF ($400,000)
- Hot water distribution system — 3,500,000 SF ($1,400,000)
- Steam distribution system to chemical plant — 500,000 SF ($200,000)

Fortunately, the 1976 annual expenditures were available in detail as shown in Table 6.

Revenues

The most consistent picture can be seen in the 1977 estimate of revenues as shown in Table 7. The revenue budget has been set lower than 1976 due to expected lower costs. This table of revenues showing the 12 sources of annual revenues dramatically portrays the revenue raising potential for a single 120 tonne per day refuse fired steam generator with a standby oil boiler. Since the RFSG plant only operates 5 days per week, the standby oil boiler is regularly used. The reader is again reminded that these revenues are for the total four-building complex. Dump fees for animal waste and from sale of compost are the only revenues not tied to the RFSG.

Even in winter there are times when some steam must be condensed, which also consumes electricity for driving the condenser fan. In 1978 the heating system was to be extended which will increase revenues with same increase in amortization.

TABLE 1-5. WERDENBERG PLANT COSTS, 1976

	Swiss Francs	
	Expense	Revenue
Operating Expense	60,223.60	
Capital Costs	81,626.07	
Maintenance and Repair		
Building Maintenance	5,178.20	
Equipment Maintenance	5,633.35	
Compost Facilities	1,481.50	
Refuse Burning Plant	96,582.15	
Animal Incineration	131.20	
District Heating Lines	96.00	
Tools and Furniture	218.80	
Trax (?)	6,008.50	
TOTAL	115,379.70	
Depreciation	1,685,998.15	
Insurance	85,795.00	
Supplies		
Electricity	58,711.30	
Miscellaneous Supplies	8,386.35	
Diesel Oil	4,426.65	
Heating Oil and Gas	235,171.35	
Cleaning Materials	1,461.00	
Lubricants	2,310.30	
Chemicals	3,734.00	
TOTAL	314,700.95	
Administration	13,330.20	
Landfill and Hauling		
Front-end loader, rental		244.45
Truck rental		430.95
Scrap Iron Disposal	45,360.50	
Gretschans Landfill	2,275.00	
Buchserbert Landfill	81,354.75	
TOTAL	128,314.85	
Miscellaneous Expense	5,219.10	
Special Expense		
Canal Connection	80,103.95	
General Fees		3,384,848.75
Sale of Compost		467.80
Sale of Scrap Iron		9,555.10
Used Oil Processing		27,208.77
Sale of Heat		346,401.45
Sale of Electricity		60,297.25
SUBTOTALS	3,832,691.57	3,828,779.12
BALANCE		4,291.10
BUDGET PLANNING	578.65	
TOTAL	3,833,070.22	3,833,070.22

TABLE 1-6. REVENUE ESTIMATE FOR 1977

Revenue Category	Annual Volume	Charge Old (S.Fr.)	Charge New (S.Fr.)	New Revenue (S.Fr.)
Dump Fee Household & Bulky Waste	20,000 Tonnes	90	80	1,600,000
Dump Fee, Industrial Waste	3,000 Tonnes	120	100	300,000
Dump Fee, Animal Waste	300 Tonnes	150	150	45,000
Dump Fee, Scrap Iron	150 Tonnes	200	200	30,000
Subsidized Head Tax	76,685 People	12	10	766,850
Sale of Compost (1976 data)				468
Sale of Scrap Iron				5,000
Sale of Waste Oil				25,000
Sale of Warm Water (District Heating				} 320,000
Sale of Steam (Chemical Industry Process Steam)				
Sale of Electricity (1/2)				} 50,000
Internal Credit for Electricity (1/2)				
TOTAL REVENUES				3,142,318

Werdenberg-Liechtenstein Plant, Courtesy of the Society for Refuse Disposal, 1976 Annual Report, Widmer + Ernst (Alberti-Fonsar)

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
feet	meters	0.3048	meters	feet	3.281
square feet	square meters	0.0929	square meters	square feet	10.76
cubic feet	cubic meters	0.0283	cubic meters	cubic feet	35.31
inches	millimeters	25.4	millimeters	inches	0.0394
cubic yards	cubic meters	0.7646	cubic meters	cubic yards	1.308
barrels (oil)	cubic meters	0.15899	cubic meters	barrels (oil)	6.290
miles	kilometers	1.609	kilometers	miles	0.6214
square miles	square kilometers	2.589	square kilometers	square miles	0.3861
acres	square kilometers	0.004047	square kilometers	acres	247.1
acres	hectares	0.4047	hectares	acres	2.471
gallons	cubic meters	0.003785	cubic meters	gallons	264.2
ton (short)	tonne (metric)	0.9078	tonné (metric)	ton (short)	1.102
pounds	grams	454	grams	pounds	0.002046
grains	grams	0.0648	grams	grains	15.42

Revised Dec. 78

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2
pounds per million Btu	milligrams per megajoule	499.2
cubic feet per minute	cubic meters per hour	1.699
gallons per minute	liters per minute	3.785
pounds per square foot	kilograms per square meter	703.1
pounds per square inch	kilograms per square centimeter	0.07031
pounds per square inch	atmospheres	0.0681
pounds per square inch	newtons per square meter	6894.8
pounds per square inch	kilopascals	6.8948
atmospheres	bars	1.0133
atmospheres	kilopascals	101.3
pounds per square inch	bars	0.06895
inches of water	pascals	249.08
millimeters of water	pascals	9.806

To Convert From	To Get	Multiply by
nanograms per Joule	pounds per million Btu	0.0023
milligrams per megajoule	pounds per million Btu	0.00233
cubic meters per hour	cubic feet per minute	0.588
liters per minute	gallons per minute	0.264
kilograms per square meter	pounds per square foot	0.001422
kilograms per square centimeter	pounds per square inch	14.223
atmospheres	pounds per square inch	14.69
newtons per square meter	pounds per square inch	0.00014
kilopascals	pounds per square inch	0.1450
bars	atmospheres	0.9869
kilopascals	atmospheres	0.0098
bars	pounds per square inch	14.50
pascals	inches of water	0.004015
pascals	millimeters of water	0.102

Revised Dec. 78

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252	kilocalorie	Btu	3.968
MBtu	Gcal	0.252	Gcal	MBtu	3.968
Btu	kilowatt-hours	0.000293	kilowatt-hours	Btu	3414
Btu	Joules	1055.1	Joules	Btu	0.000948
Btu per pound	kilocalories per kilogram	0.5555	kilocalories per kilogram	Btu per pound	1.8
Btu per pound	Joules per kilogram	2326	Joules per kilogram	Btu per pound	0.00430
Btu per hour	watts	0.29307	watts	Btu per hour	3.413
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711	kilocalories per sq meter-hr	Btu per sq ft-hr	0.3688
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897	kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
pounds per 1000 pounds(gas)	grams per cu meter	1.205	grams per cu meter (gas)	pounds per 1000 pounds	0.93
grains per cu ft (68 F)	grams per cu meter (20 C)	2.28	grams per cu meter (20 C)	grains per cu ft (68 F)	0.43

Revised Dec. 78

TABLE . EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES, (NATIONAL MONETARY UNIT PER U.S. DOLLAR) 1948 TO FEBRUARY, 1978(a)

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.300	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.202	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.

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* U. S. GOVERNMENT PRINTING OFFICE : 1979—320-007/6313